SCHOOL OF

CIVIL ENGINEERING

INDIANA

DEPARTMENT OF TRANSPORTATION

JOINT HIGHWAY RESEARCH PROJECT

FHWA/IN/JHRP-95/12

Final Report

EFFECT OF PYROLYZED CARBON BLACK ON ASPHALT CEMENT

(Part Two: Asphalt Binder)

Yongdong Zeng and C. W. Lovell

PURDUE UNIVERSITY

FINAL REPORT

USING PYROLYZED CARBON BLACK(PCB) FROM WASTE TIRES IN ASPHALT PAVEMENTS

(PART II: Asphalt Binder, and Test Road)

FHWA/IN/JHRP-95/12

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Project No: C-36-55L
File No: 2-12-13

Prepared in coorporation with the
U.S. Department of Transportation Federal Highway Adminisration

Purdue University
West Lafayette, Indiana 47907
February 20, 1996

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/IN/JHRP-95/12		

4. Title and Subtitle	5. Report Date
Using Pyrolyzed Carbon Black (PCB) from Waste Tires in Asphalt Pavements (Part II, Asphalt Binder and Test Road)	February 20, 1996
	6. Performing Organization Code
7. Author(s)	**8. Performing Organization Report No.**
Yongdong Zeng and C. W. Lovell	FHWA/IN/JHRP-95/12
9. Performing Organization Name and Address Joint Highway Research Project Civil Engineering Building Purdue University West Lafayette, Indiana 47907-1284	**10. Work Unit No.**
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Indiana Department of Transportation Indiana Government Center North 100 North Senate Avenue Indianapolis, IN 46204	**13. Type of Report and Period Covered** Final Report September, 1993 to May, 1995
	14. Sponsoring Agency Code

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Scrap tires derived from automobiles have become a large environmental problem in the United States. In this study, research is carried out to investigate the potential use of tire-derived pyrolyzed carbon black from scrap tires as an asphalt cement modifier.

The asphalt cements used in this research were AC10 and AC20. Penetration and softening point tests were performed to obtain the consistency of the asphalt cements. The pyrolyzed carbon black, as provided by Wolf Industries, was combined with the asphalt cement in the following percentages: 5%, 10%, 15% and 20%. Penetration, softening point and ductility tests were performed to determine the temperature susceptibility of the modified binder as altered by the pyrolyzed carbon black.

In order that the results are comparable to previous testing, commercial carbon black purchased from CABOT Industry was also used as a modifier in the tests. The same test procedures were applied to the asphalt cements modified by commercial carbon black.

The test results contained in this report illustrate the viability of the pyrolyzed carbon black as an asphalt modifier. Recommendations are provided to facilitate further research on this particular project.

A preliminary assessment of a test road using the pyrolyzed carbon is appended.

17. Key Words	18. Distribution Statement
scrap tires, asphalt, pyrolysis of scrap rubber, carbon black, asphaltic binder, test road	No restrictions. This document is available to the public through the National Technical Information Service, Virginia, 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	142	

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the valuable guidance provided by Dr. Coree and Mr. Travis Lovvorn, who are with Indiana Department of Transportation's Division of Research, for their assistance in using testing equipment for determining asphalt properties. Personal instruction and encouragement from Professor Salgado is highly appreciated. Also, sincere thanks are due to Mr. Lee and Dr. Park for their help and discussion.

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Chapter 1

INTRODUCTION

1.1 Background

Tire recycling has become a necessity because of the accumulation of discarded tires which has become a potential environmental risk. There are approximately 240 million waste tires generated annually in the United States [S. N. Amirkhanian, 1993]. Of these, 200 million are passenger car tires and the other 40 million are truck tires. While some of these tires are recapped or ground into crumbs for special uses, most are dumped in rural areas or in landfills, which will pose serious environmental problems or use space needed for municipal solid wastes.

Scrap tires, can on the other hand, represent a source of energy and chemicals. By thermal decomposition, it is possible to recover useful products. Although the end products differ, depending on the types and the efficiency of processing plans, typical yields from scrap tires are approximately 30% light hydrocarbons which can be refined and serve as fuel, 25% carbon black, 15% gas, 10% steel, 5% sludge and 2% water. The carbon black derived from used tires contains several impurities, which makes it difficult to be reused commercially.

The inclusion of additives in pavement materials as reinforcing agents has been

studied for a long time. The feasibility of a variety of modifiers has been investigated in the laboratory as well as in field demonstrations. Some of these, such as limestone dust, hydrated lime and portland cement produce more or less an improvement in pavement properties when added into the asphalt concrete.

Carbon black of pure form has been used as a reinforcement in tires to increase the service life of tires. A similar concept of applying carbon black to reinforce asphalt cement was first reported in the early 1960's [Allioti 1962, Martin 1962]. Since then, several research studies have been undertaken. The results show some positive effects, and no adverse effects due to the use of carbon black have been reported. But the carbon black used in research thus far is comprised largely of pure carbon in pelletized or microfil form.

1.2 Problem Statement

Recent research has enabled some companies to commercialize a process which pyrolyzes scrap tires at high temperatures. The products include gas and liquid fuel, steel, and a large particle size carbon- black-like material. Using this carbon black instead of crumb rubber in pavement materials could accomplish the same basic objective of disposal of scrap tires. The use of carbon black in asphalt concrete could result in substantial saving as compared with crumb rubber. The pyrolyzed carbon black from scrap automobile tires is comprised of only about 75% pure carbon. Therefore, it is necessary to study the effect of this pyrolyzed carbon black on the properties of asphalt binder.

1.3 Objectives

Laboratory studies are needed to verify the technical viability of the pyrolyzed carbon black as a modifier in asphalt binder. For the purpose of comparison, both carbon black and pyrolyzed carbon black were used as the additives in the studies. Research involved in this project includes the following aspects:

(1) General characteristics of carbon black and pyrolyzed carbon black.

(2) Properties of asphalt cement employed in the research, AC10 and AC20.

(3) Improvement of the properties of asphalt modified by pyrolyzed carbon black.

(4) The aging properties of asphalt modified by carbon black and pyrolyzed carbon black.

(5) Penetration tests , ring and ball softening point tests and ductility tests required to define the temperature susceptibility of modified asphalt binder at high temperatures.

1.4 Report Organization

This report includes five chapters. Chapter 2 reviews the general properties of the carbon black and asphalt cement. Current research on the modification of the properties of asphalt due to the inclusion of carbon black are summarized in this chapter. Chapter 3 and Chapter 4 contain a description of the materials, tests, equipment and procedures employed in this study. Chapter 5 contains test results and evaluation of pyrolyzed carbon black as a filler in original asphalt and aged asphalt cements. Chapter 6 contains the conclusions and the recommendations.

Appendix A contains experimental data, and Appendix B is a preliminary assessment of a test road using pyrolyzed carbon black.

1.5 Implementation

The implementation of this study will provide INDOT information about the feasibility of carbon black and pyrolyzed carbon black as new kinds of asphalt additives. The test results included in this report will show the modification of the properties of asphalt due to carbon black. The laboratory test procedures employed in this research will be a guideline for the mix design of asphalt concrete. The use of pyrolyzed carbon black will potentially result in the saving of tax dollars.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

Numerous waste materials result from manufacturing operations, service industries, sewage treatment plants, households and mining. They can be broadly categorized as (a) Industrial waste, such as fly ash; (b) Municipal/domestic waste, such as scrap rubber, and (c) Mining waste, such as coal mine refuse [Kandhal, 1993]. The use of waste materials as pavement additives has been and still is being studied technically. The purpose of this research includes the gathering and reporting of information on the design, construction, performance and cost effectiveness of different asphalt additives for use in bituminous concrete pavements.

Many promising types of asphalt additives have been studied. Findings from these studies clearly show that no single asphalt additive is a cure-all. However, the results indicate that certain selected additives have the potential to provide cost-effective extensions to pavement service life [Rostler et al, 1977; Vallerga and Gridley, 1980].

The use of carbon black as an additive in bituminous pavements to enhance performance has been investigated by many researchers since the 1960's [Allioti, 1962; Rostler et al, 1977; Vallerga and Gridley, 1980]. Carbon black has been used to improve

binder properties, so that cracking at low temperatures and rutting at high temperatures is reduced. The carbon black featured in this study is derived from waste tires. It is believed that recycling of waste tires in this way is not harmful to the environment.

In this chapter, research on asphalt additives will be summarized. The features of carbon blacks and their effects on the properties of asphalt binder will be reviewed briefly.

2.2 Overview of Asphalt Additives

Most of the known asphalt additives available currently have been categorized by generic name as [Button, 1992]:

1. Polymers
2. Extenders
3. Mineral Fillers
4. Natural asphalt
5. Antioxidants
6. Antistripping agents
7. Hydrocarbon
8. Fibers

Some of these are used routinely in bituminous paving mixtures; others are still in the experimental stage.

Polymers are the most versatile, and probably hold more promise to improve structural and adhesive properties of the bituminous pavements than any other additives. The results from laboratory tests and field demonstrations show that polymer additives are able to reduce binder temperature susceptibility and brittleness and increase toughness and tenacity of the pavements.

More than 30-year experience on latexes has led to their widespread use in the paving industry. The primary reasons lie in their availability and relative cost compared with

competing polymers, and their ability to improve the consistency of the asphalt binder [Button & Little, 1988].

Asphalt rubber has been tested extensively in highway pavements. This product is composed of ground tire rubber, typically ground to a minus number 10 sieve size. The use of rubber in asphalt is observed to increase the ductility of asphalt to some extent.

Most of the additives studied improve the temperature susceptibility of an asphalt. Of course, this modification in the rheological properties of asphalt depends on the type of the additive and asphalt, and the quantity of the additive added.

2.3 Properties of Carbon Black

Carbon black is manufactured by a partial combustion process. Its main use is in the rubber industry, which consumes almost two-thirds of the total carbon black. Another important use for carbon black is in polyethylene, where it is added in amounts of 10% to 30% for protection against sun and weather. The utility of carbon black as a reinforcing agent for rubber was first discovered about 1915. The impact of using carbon black instead of zinc oxide as tire reinforcement is tremendous. The use of carbon black as a reinforcing agent for asphalt cement may result in a similar advantage [Rostler et al, 1977].

About 40 specification grades of carbon black are manufactured for the rubber, ink and plastics industries. Surface area and structure are two basic characteristics used to classify carbon black. Surface area is determined by nitrogen or iodine absorption. The structure is measured by the absorption of a liquid, such as dibutyle phthalate. The higher the degree of structure, the larger the amount of the liquid absorbed into the voids in the

bulk powder. Most commercially available carbon blacks have mean particle diameters in the range of 100 to 500 nanometers and surface areas of 15 to over 100 m^2/g. A well known filler for asphalt concrete, ground limestone, has a mean particle diameter of 35,000 nanometers and a surface area of less than 4 m^2/g. Since an individual particle of carbon black can not be seen with an ordinary optical microscope, Figure 2.1 shows the electron micrograph of a carbon black useful for asphalt cement reinforcement. Photomicrographs of clay, ground limestone and portland cement are illustrated in Figure 2.2 for comparison.

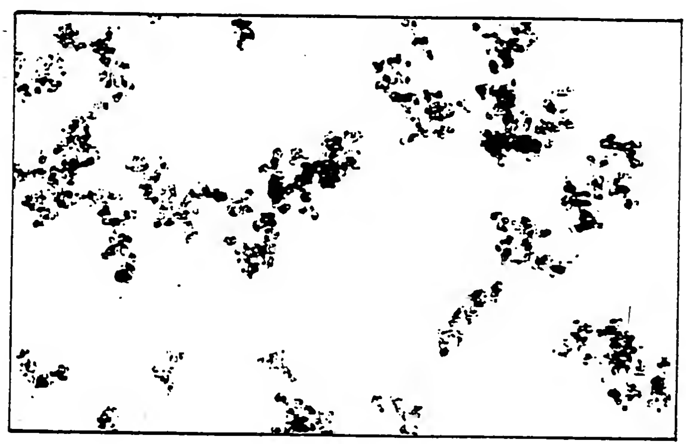
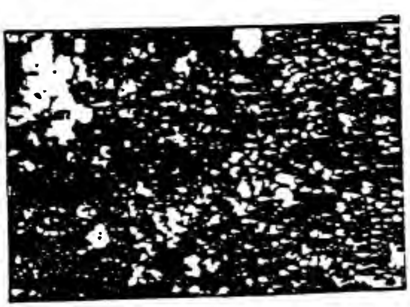
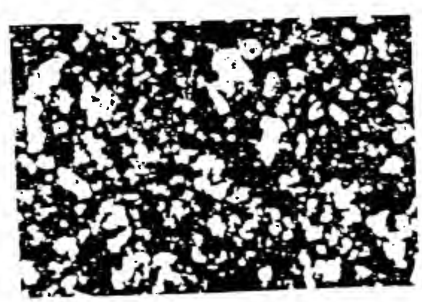


***Figure 2.1 High structure type carbon black** (after Rostler et al, 1977)*

Clay



Ground limestone



Portland cement

Figure 2.2 Structures of clay, ground limestone and portland cement (after Rostler et al, 1977)

The other properties that distinguish carbon black from conventional mineral fillers are [Donnet & Voet, 1976; Allioti, 1962]:

1. Carbon black is a hydrophobic material, while conventional fillers are hydrophilic.
2. All commercial grade carbon blacks are nearly pure carbon black, containing less than 3% impurities, while most mineral fillers are a mixture of a variety of diverse chemical compounds.
3. The particle aggregates of carbon black have an infinite variety of geometric forms, from clustered to branched and filamentous configurations.

The effect of carbon black on asphalt properties will be presented in the next section. But the carbon black from the pyrolysis of the waste tires is not necessarily pure . The product from Wolf Industries, Inc, a company in the state of Indiana which utilizes the process of pyrolysis to dispose of scrap tires, is composed of 75% carbon black and 25% of other impurities. No laboratory result has so far been reported about the modification of asphalt properties effected by this kind of carbon black. And, therefore, the main purpose of this project is to define these modifications due to the inclusion of pyrolyzed carbon black.

2.4 General Properties of Asphalt

Asphalt cement is a dark brown to black cementitious material that is either naturally occurring or is produced by petroleum distillation. Commercial types of asphalt can broadly be classified into two categories: natural asphalt and petroleum asphalt [Robert et al, 1991]. Most of the asphalt cement used in the construction of flexible pavements is obtained by the

distillation process from crude petroleum using different refining techniques.

Two methods, penetration and viscosity are used to classify asphalt cement into different grades.

The penetration grading of asphalt cement is according to ASTM D946. Five standard penetration graded asphalt cements, 40-50, 60-70, 85-100, 120-150, and 200-300 are used for paving grade asphalt. The higher the penetration, the softer the asphalt cement. The ASTM requirements for penetration graded asphalt cements are tabulated in Table 2.1

Table 2.1 ASTM requirements for penetration graded asphalt cements

	Penetration Grade									
	40-50		60-70		85-100		120-150		200-300	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Penetration at 77F 100g,5sec	40	50	60	70	85	100	120	150	200	300
Flash point,F	450	--	450	--	450	--	425	--	350	--
Ductility at 77F, 5cm/min,cm	100	--	100	--	100	--	100	--	100	--
Solubility in trichloroethylene%	99.0	--	99.0	--	99.0	--	99.0	--	99.0	--
Retained Penet after aging, %	55+	--	52+	--	47+	--	42+	--	37+	--
Ductility at 77F after aging	--	--	50	--	75	--	100	--	100	--

The viscosity grading of asphalt is specified in ASTM D3381; it is based on the viscosity of the original asphalt cement or aged asphalt cement. The viscosity grades based on the viscosity of original asphalt cements include AC2.5, AC5, AC10, AC20, AC30 and AC40. The grades based on asphalt residue after aging are AR1000, AR2000, AR4000, AR8000and AR16000. The ASTM requirements for grading are shown in Table 2.2.

The consistency tests of the asphalt cement will be addressed in detail in the following chapters.

Table 2.2 ASTM requirements for viscosity graded asphalt cements (D3381-83)

Table 1 Requirement s for asphalt cement, viscosity graded at 140°F (Based on original Asphalt)

	Viscosity grade				
	AC2.5	AC5	AC10	AC20	AC40
Viscosity, 140°F, P	250±50	500±100	1000±200	2000±400	4000±800
Viscosity, 275°F min.cSt	80	110	150	210	300
Penetration,77°F 100g,5sec	200	120	70	40	20
Flash point, °F	325(163)	350(177)	425(219)	450(232)	450(232)
Solubility in trichloroethylene%	99.0	99.0	99.0	99.0	99.0
Test on residue after aging					
Viscosity, 140°F,P	1250	2500	5000	10,000	20,000
Ductility,77°F,5cm/min.cm	100	100	50	20	10

Table 2 Requirement s for asphalt cement, viscosity graded at 140°F (Based on original asphalt)

	Viscosity grade					
	AC2.5	AC5	AC10	AC20	AC30	AC40
Viscosity, 1400°F, P	250±50	500±100	1000±200	2000±400	3000±600	4000±800
Viscosity, 275°F min.cSt	125	175	250	210	350	400
Penetration,77°F 100g,5sec	220	140	80	40	50	40
Flash point, °F	325(163)	350(177)	425(219)	450(212)	450(232)	450(232)
Solubility in trichloroethylene%	99.0	99.0	99.0	99.0	99.0	99.0
Test on residue after aging						
Viscosity, 140°F,P	1250	2500	5000	10,000	15,000	20,000
Ductility,77°F,5cm/min.cm	100	100	75	50	40	25

Table 3 Requirements for asphalt cement, viscosity graded at 140°F (Based on asphalt residue)

	Viscosity grade				
	AR1000	AR2000	AR4000	AR8000	AR16000
Viscosity, 140°F, P	1000±250	2000±500	4000±1000	8000±2000	16,000±4000
Viscosity, 275°F min.cSt	140	200	275	400	550
Penetration,77°F 100g,5sec	65	400	25	20	20
% of original asphalt 77°F,min		40	45	50	50
Ductility 77°F 5cm/min,cm	100	100	75.0	75.0	75
Test on original asphalt					
Flash point, °F	400(205)	425(219)	440(227)	450(232)	460(238)
Solubility in trichlo.%	99.0	99.0	99.0	99.0	99.0

2.5 Effect of Carbon Black on Asphalt Properties

The conventional asphalt concrete mixture contains three ingredients: (1) aggregate, which is the component larger than the 200 mesh sieve size(0.074mm), (2) filler, which is comprised of microaggregate passing 200-mesh sieve size, and (3) asphalt cement. The use of carbon black as a reinforcing agent for asphalt introduces a new dimension in the design of asphalt concrete mixtures. The size of the carbon black suggested for use in asphalt has an equivalent spherical diameter of about 100 to 150 nanometers so that it can be dispersed and completely imbedded in asphalt binder. Compared to limestone fillers, this size is quite small.

A two dimensional representation of a carbon black particle is shown in Figure 2.3.

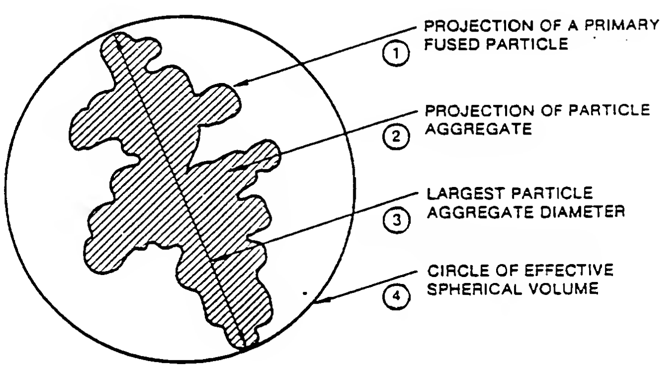


Figure 2.3 Illustration of a carbon black particle(after Rostler et al, 1977)

The importance of filler dimensions and asphalt wettability has been reported by Anderson and Goetz [1973]. According to their research, carbon black can be preferentially wetted by hydrocarbon types of fluid, such as asphalt, because the size of the particle is very small and its surface is hydrophobic. When properly dispersed, the carbon black is made a part of the asphalt cement. As a contrast, mineral fillers actually act as a fines fraction of the total aggregate in the pavement mixture.

Dispersion of carbon black is very important. If it does not disperse during mixing, the carbon black pellet fragments act as absorbent fillers, creating an increased demand for asphalt cement, just like mineral filler. If on the other hand, the carbon black is fully dispersed in the asphalt cement, it increases the volume of cementing agent without increasing bleeding tendency or affecting stability. The role of carbon black, filler aggregate and asphalt cement in an asphalt concrete mixture is illustrated schematically in Figure 2.4.

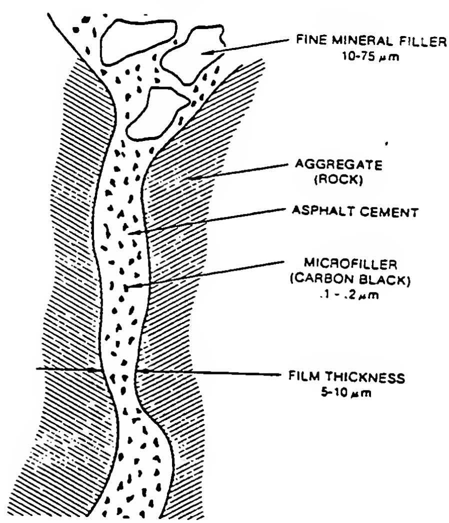


Figure 2.4 Components of asphalt concrete mixture (after Rostler et al, 1977)

Laboratory tests were carried out by Rostler et al, 1977 to study the effect of carbon black on asphalt cement properties. The carbon black was carefully mixed so that full dispersion was achieved. Two main kinds of tests, namely the Brookfield viscosity test and the penetration test were performed. The reference asphalt used was BPR 349, which has a penetration of about 60 at 77^{0}F (25^{0}C). The carbon black employed in the tests was high structure, high abrasion furnace black. The mean particle dimension was 26 nanometers; surface area was 90 cm^2/g.

The test results in Figure 2.5 show that the viscosity of the mixture increases steadily with the increase in added carbon black. The results of penetration tests illustrated in Figure 2.6, also indicate that the penetration at 77^{0}F decreases rapidly with the increase of the carbon black percentage.

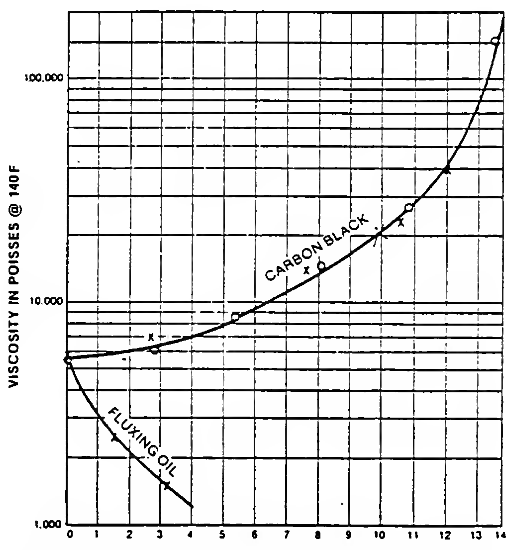


Figure 2.5 Test results of viscosity versus carbon black percentage (after Rostler et al, 1977)

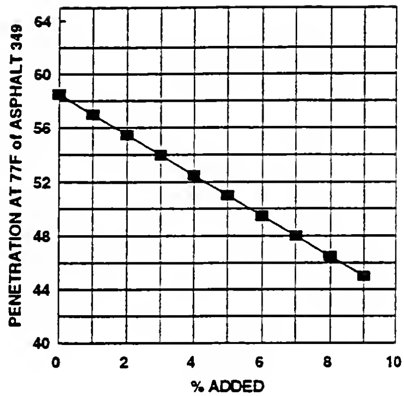


Figure 2.6 Test results of penetration versus carbon black (after Rostler et al, 1977)

Vallerga and Gridley (1980) showed beneficial effects of carbon black on the durability and the temperature-viscosity susceptibility of asphalt. The decrease in temperature susceptibility of asphalt with the addition of carbon black suggests that its use will increase the resistance to high temperature distortion and low temperature cracking of asphalt pavements.

2.6 Chapter Summary

Previous research focused mainly on carbon black comprised of largely pure carbon. More extensive and specific tests will be reported in the following chapters on asphalt cement modified by pyrolyzed carbon black, which typically contains about 75% pure carbon.

Chapter 3

MATERIAL PROPERTIES

3.1 Introduction

In the previous chapter, the general properties of carbon black, asphalt and the effect of carbon black on asphalt properties have been described. In this chapter, the specific properties of the materials used in this research will be addressed:

1. The characteristics of carbon black from the pyrolyzed process of waste tire.
2. Properties of commercial carbon black.
3. Consistency of the asphalt cements employed in the study.

3.2 Carbon Black

To provide a comparison for the effect of pyrolyzed carbon black on asphalt properties, commercial carbon black is also utilized in this study. The carbon black was purchased from CABOT Industry, Boston, Massachusetts.

There are four types of carbon black, namely, furnace black, channel black, thermal black and lamp black. Furnace black is available from a furnace by partial combustion of hydrocarbon. As is described in the previous chapter, the performance of carbon black is classified according to its particle size and surface area as shown in figure 3.1. The carbon black used in this study is high structure, high abrasion furnace type carbon black. This

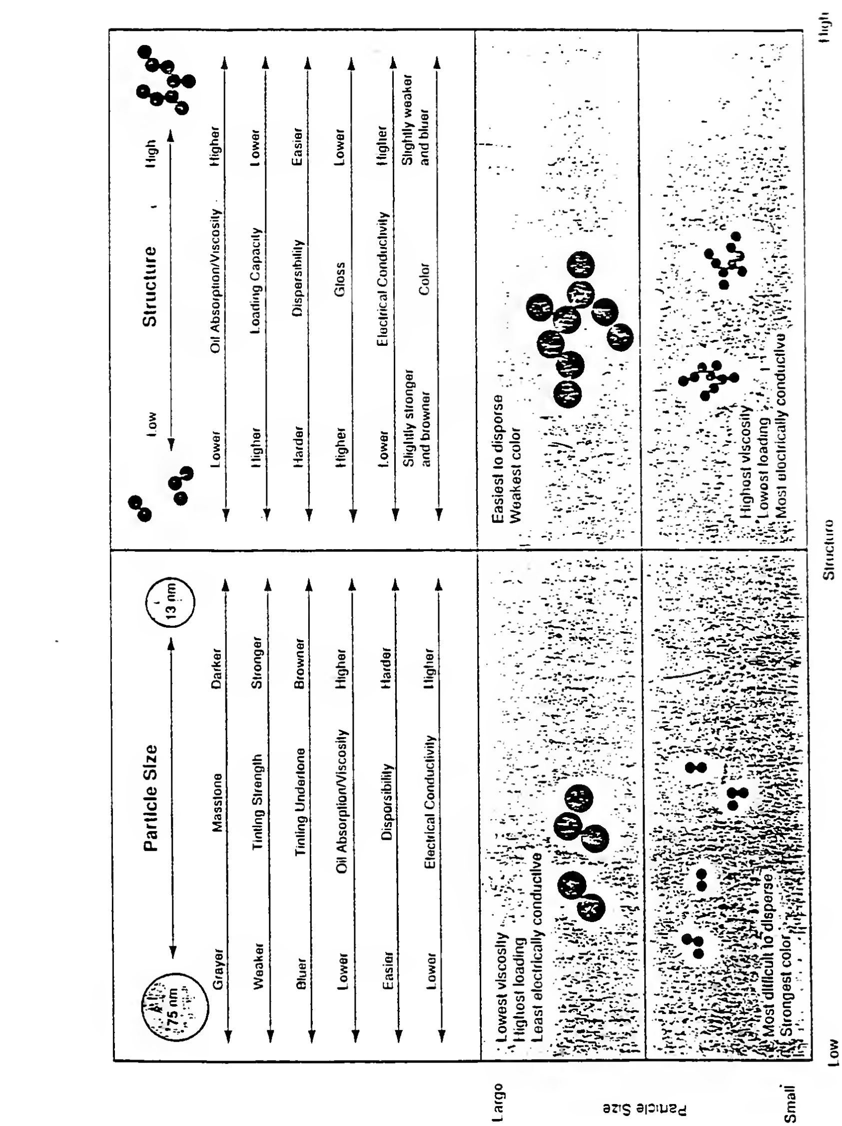


Figure 3.1 Characteristics of carbon black and its particle size and surface area(after Cabot, 1994)

kind of carbon black has been used by a number of researches [Yao &Monismith, 1986, Vallerga & Gridley, 1980, Rostler et al, 1977] as an additive in asphalt cement. The results indicated improvement of the properties of asphalt binders.

The typical characteristics of this carbon black provided by CABOT Industry are tabulated in Table 3.1

Table 3.1 Characteristics of carbon black used in the study(after Cabot, 1995)

Properties	Specification
Iodine Index (mg/g)	76±5
DBP absorption (cc/100g)	85±5
Tint strength (% ITBR)	113±3
Ash (%)	1.0 max
Density (lb/ft^3)	12.5±3
Particle size (nm)	100~500
Surface area (m^2/mg)	15~100

3.3 Pyrolyzed Carbon Black

The pyrolyzed carbon black used in the research is provided by Wolf Industries, Indiana, which aimed at obtaining hydrocarbon fuel from the waste scrap tires. The tires are decomposed by burning at high temperature. The main products from the process include carbon black and oil.

3.3.1 Techniques of tire pyrolysis

Pyrolysis is a process to decompose the scrap waste tires. The waste tires were broken down at high temperature into salable products. There are many different techniques of tire pyrolysis. The producing process is shown schematically in Figure 3.2 [Roy et al, 1990]. The carbon black used in this project is obtained from the reductive pyrolysis process.

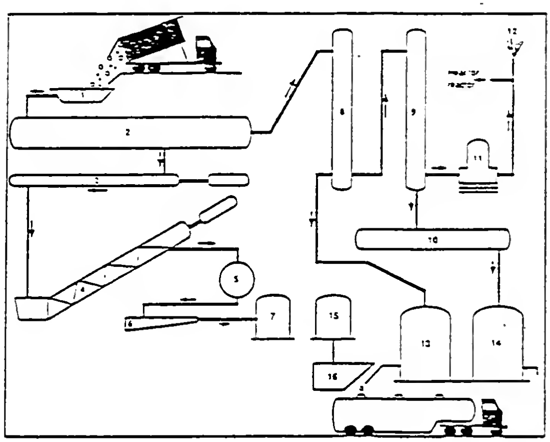


Figure 3.2 Pilot plant of tires pyrolysis *(After Roy et al, 1990)*

[1. Feed conveyor; 2. Vacuum reactor; 3. Cooling screw; 4. Discharge screw; 5. Crusher; 6. Vibratory screen; 7. Carbon black handling system; 8. Heavy oil quencher; 9. Light oil quencher; 10. Decanter; 11. Vacuum pump; 12. Flare stack; 13. Heavy oil storage; 14. Light oil storage; 15. Magnetic separator; 16. Steel recovery bin.]

The general properties of a carbon black sample produced during vacuum pyrolysis of used tires are listed in Table 3.2

Table 3.2 general properties of pyrolyzed carbon black from pilot plant *(After Roy et al, 1990)*

Properties	Specification
Iodine index (mg/g)	144.2~151.4
DPB absorption (ml/100g)	84.6~93.0
Heat loss at 105^{0}C (%)	0.4~1.0
Tint strength (% ITRB)	57.1~60.6
Ash (%)	15.5~17.0
Volatile matter (%)	4.0~3.3
Sulfur (%)	2.5~3.0

According to the research of Roy, the end-products of tires pyrolysis depends greatly on the temperature of decomposition. If the pyrolysis is performed at low temperature, the yield of oil and water decreases, while the quantity of carbon black increases. The phenomena is shown in Figure 3.3.

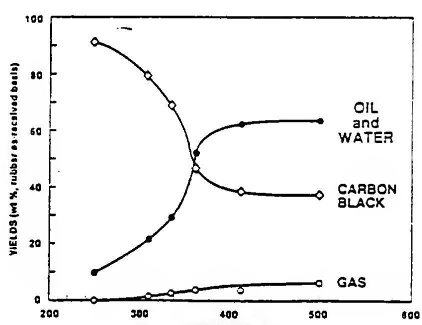


Figure 3.3 Influence of decomposition temperature on pyrolysis yields *(after Roy et al, 1990)*

3.3.2 Characteristics of pyrolyzed carbon black used

The carbon black used in this study is provided by Wolf Industries. It is obtained from the reductive pyrolysis process. The procedures are summarized by Park(1995), as shown in Figure 3.4. The carbon black used is a grey to black powder. Its particle size is much larger than that of commercial carbon black. This is carbon black has a higher specific gravity than commercial carbon black. It is insoluble in water. Partial clods can be observed, but there are easily broken down.

The data provided by Wolf Industries in Table 3.3 indicate the following particle sizes and surface areas fro typical products.

Table 3.3 Particle sizes and surface areas of pyrolyzed carbon black (Mill ground)

Name of products	Rg(A),Particle size	Surface area(gm/mg^3)
BC 100	430	157
BC 200	343	188
BC 500	439	159
WC 500	230	338
*NC 339	304	187

Note: NC339 is a pure carbon black listed for comparison.

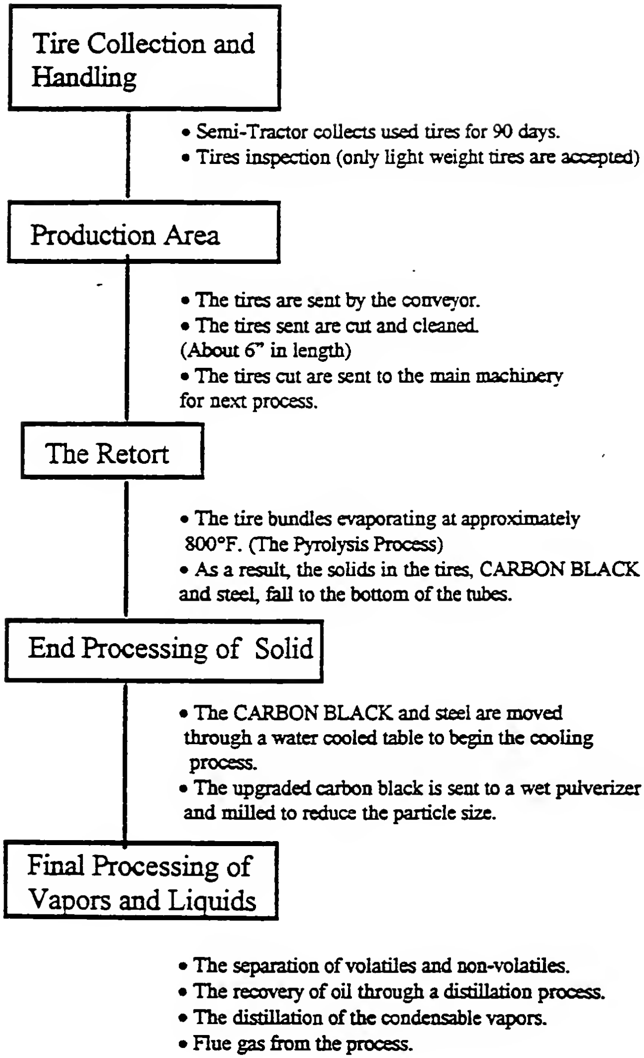


Figure 3.4 Process of waste tire pyrolysis by Wolf Industries (Park, 1995)

3.4 Asphalt Cement

The most commonly used asphalt cements for pavement construction in the United States are AC10 and AC20. Most of the flexible pavements in Indiana were also constructed using AC10 and AC20. Consequently, it is reasonable to use these two kinds of asphalt.

The physical properties of AC10 and AC20, including the requirements of specifications and results of our tests are listed in Table 3.4.

Table 3.4 Properties of asphalt cement used in this study

Test	AC10		AC20	
	Required	Result	Required	Result
Penetration @ 77^0F, 100g, 5 sec.	70-140	101	50-110	65
Kinematic viscosity @ 275^0F, cSt	250	289	300	396
Absolute viscosity @ 140^0F, poise	4000*	---	8000*	---
Flash point, cleveland open cup, ^{0}C	218	---	232	---
Solubility in organic solvents, %	99.0	---	99.0	---
Ductility @ 77^0F,. 5cm/min,cm	60*	65	40*	50

(Note: * Absolute viscosity and Ductility test results are from residue of thin-film oven test.)

3.5 Chapter Summary

Physical and chemical properties of the materials were described in detail to enable understanding of the behavior of the carbon black, pyrolyzed carbon black and asphalt cements which were to be used in this study. A brief discription of the pyrolysis of carbon black from waste tires was also given.

Chapter 4

DESIGN OF TESTING

4.1 Introduction

To study the effect of carbon black and pyrolyzed carbon black on the properties of asphalt, consistency tests should be performed on both the original asphalt and the modified asphalt cements. Specific gravity tests, penetration tests, ring and ball softening point tests will be described.

4.2 Specific Gravity Test

4.2.1 Background

Specific gravity of asphalt is the ratio of the mass of a given volume of the material at 77^0F or at 60^0F to that of an equal volume of water at the same temperature. Values of specific gravity are used for converting volume to unit of mass.

4.2.2 Test equipment

A pycnometer is the main apparatus used in the test. The stopper of the pycnometer is accurately fitted with a hole 1.0 to 2.0 mm in diameter located centrally in the stopper so that air is allowed to escape through the hole.

A water bath is necessary for constant temperature control. A thermometer is suspended in the water bath which indicates the temperature of the bath.

4.2.3 Test procedure

Heat the asphalt sample with caution for about 30 minutes until the sample is fluid enough to pour. Be careful not to overheat the sample.

Pour the sample into a dry, clean pycnometer to its three-fourth capacity. Operate carefully to avoid inclusion of air bubbles in the sample. Cool the pycnometer filled with asphalt to ambient temperature for about 40 minutes and weigh with the stopper to the nearest 1.0mg.

Place the pycnometer with asphalt into a water bath and fill it with distilled water; press the stopper firmly. Allow the pycnometer to remain in the water bath for about 30 minutes. Dry and weigh the pycnometer.

The specific gravity of asphalt is:

$$G=\frac{C-A}{(B-A)-(D-C)}$$

In the above equation,

G= Specific gravity;

A= Weight of pycnometer (plus stopper);

B= Weight of pycnometer filled with distilled water;

C= Weight of pycnometer plus asphalt;

D= Weight of pycnometer plus asphalt and water.

According to ASTM D70, the results of two properly conducted tests by the same operator should not differ by more than 0.002.

4.3 Kinematic Viscosity Test

4.3.1 Background

Viscosity at any given temperature and shear rate is essentially the ratio of shear stress to shear strain rate. This coefficient is a measure of the resistance to flow of a liquid. Kinematic viscosity is the ratio of viscosity to the density of a liquid, and is a measure of the resistance to flow of a liquid under gravity. At low temperature, asphalt has non-Newtonian flow, while at high temperature, it follows simple Newtonian flow.

The viscosity at 275^{0}F is specified because this temperature is approximately the mixing and laydown temperatures used in the construction of hot mix asphalt pavements. In addition, the viscosity at this temperature is independent of the details of test procedure and sample preparation.

4.3.2 Test equipment

The major piece of apparatus's is a viscometer. The Zeitfuchs cross-arm viscometer was used in this testing. It is capillary-type and made of borosilicate grass. The calibration factor of the viscometer is supplied by the manufacturer.

Another essential piece of equipment is an oil bath, which is capable of maintaining the temperature at 275^{0}F. The bath used in this study is able to perform six viscosity tests at the same time.

An electric timer is provided to define the time elapsed for the asphalt to flow between the bottom and the top timing marks.

4.3.3 Test procedure

Heat the asphalt sample until it is sufficiently fluid to pour. Maintain the oil bath temperature at $275^0 \pm 0.05^0$F. Preheat the viscometer to the test temperature by inserting it into the bath.

Charge the viscometer with asphalt until it reaches the filling line. The viscometer is then kept in the bath for about 30 minutes to reach the equilibrium temperature.

A slight vacuum is applied to the small opening to induce the flow of asphalt cement over the siphon section just above the filling line. Asphalt will begin to flow downward due to gravity.

Begin timing when asphalt reaches the bottom timing mark and stop when it reaches the top timing mark on the other side of capillary tube.

The kinematic viscosity in centistocks is obtained by multiplying the time by the calibration factors.

4.4 Penetration Test

4.4.1 Background

Penetration testing has long been used to identified the consistency of materials by penetrating to a defined indentation. Penetration testing for bituminous materials (ASTM D-5) is used to measure the consistency of asphalt material, expressed as the distance in tenths of a millimeter that a standard needle vertically penetrates a sample of the material under known condition of loading, time and temperature.

Penetration values are necessary for the classification of asphalts, and are also used

to determine the temperature susceptibility of asphalt cement in terms of penetration index. Penetration decreases with the aging of asphalt material. Figure 4.1 illustrates the empirical relation of penetration versus life of pavement. Several conclusions were obtained concerning the effect of asphalt cement hardening on the development of cracking in hot mix asphalt pavements (Robert et al, 1990).

1. Cracking is possible when the penetration of the asphalt cement is 30 or less. Serious pavement cracking may occur if penetration is 20 or less.

2. When a mixture is well designed and properly compacted, and the penetration of the asphalt cement is well above 30, high resistance to cracking is expected.

3. To prevent displacement of pavement under traffic and ensure long service life, as soft an asphalt cement as possible which meets the stability requirement shall be used.

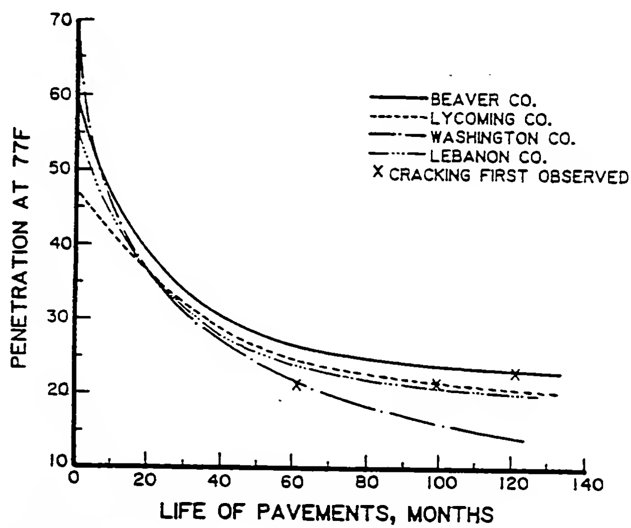


Figure 4.1 Relation between penetration and service life of asphalt pavement (Robert et al, 1990)

4.4.2 Test equipment

A spindle is used to hold and relieve the needle and to permit it to move vertically without measurable friction. The spindle shall be able to indicate the depth of penetration to the nearest 0.1mm. It is required that the weight of the spindle be 47.5±0.05g, and the total weight of the needle and spindle be 50±0.05g.

A penetration needle shall be made of fully hardened and tempered stainless steel. It is approximately 50mm in length and 1.00 to 1.02 mm in diameter. The size requirement for the penetration needle is specified in ASTM D-5.

An automatic timing device attached to the penetrometer is used in the test. The timer is accurately calibrated to provide a time interval of five seconds.

The same water bath as is used in specific gravity testing is provided in this test to maintain the temperature at a specific testing temperature.

Two kinds of sample containers, metal containers and plastic containers with two ends open are used for special tests. The objective of using these plastic containers will be described in the following chapter.

4.4.3 Test procedure

Heat the sample until it has become sufficiently fluid to pour. Pour the sample into the container to a depth adequate for the test when cooled. Place the sample container in ambient temperature for about 1 to 1.5 hours to cool down.

Put the sample into the water bath which is maintained at temperature of test for 30 minutes. At the same time prepare the penetrometer.

Transfer the sample with water to penetrometer and make at least four determinations.

Be sure that the difference between the highest and lowest numbers is within the required precision.

4.5 Ring and Ball Softening Point Test

4.5.1 Background

There is no definite temperature at which asphalt changes from a solid state to a liquid state. It gradually becomes softer and less viscous as the temperature rises. For this reason, the softening point test is designed so that the results obtained can be compared. The softening point is measured by a ring and ball method in accordance with ASTM D36. It is defined as the temperature at which an asphalt cement supports the weight of a steel ball and starts to flow. The purpose of the softening point test is to determine the temperature at which a phase change occurs in the asphalt cement.

In the test, a steel ball of specific weight is placed on a dish of sample contained within a horizontally shouldered, metal ring of specified dimensions. The assembly is heated in an ethylene glycol bath at a uniform, prescribed rate and the softening point is taken as the temperature at which the sample becomes soft enough to allow the ball to fall a distance of 25.4 mm.

The softening point is used to classify the asphalt, and is an indication of the tendency of the material to flow at elevated temperatures.

4.5.2 Test equipment

The softening point test is performed on an assembly of apparatus including rings, balls, ball centering guides and ring holders. The specific sizes of each components are

described in AASHTO T53-89.

A liquid bath of ethylene glycol is used to raise the temperature of the sample. The boiling point of the liquid is between 379^{0}F and 398^{0}F.

A thermometer is used and shall be suspended so that the bottom of the bulb is level with the bottom of the rings.

4.5.3 Test procedure

Heat the sample until it is fluid enough to pour; prevent local overheating. In the meanwhile, place the ring on a base plate coated with grease.

Fill the rings with molten sample to an excess height above each ring. Cool the sample in the air for 30 min and then level the specimens in the rings by cutting away the excess parts with a warmed knife.

Assemble the apparatus, and place the rings in the position with ball guides. Maintain the bath temperature at 39.2$^0\pm$2^{0}F for 15 minutes. Place the balls cooled in the bath into the ball guides.

Heat the bath so that the temperature rises evenly at a rate of 5$^0\pm$0.5^{0}C per minute. Record the temperature at the instant asphalt surrounding the ball touches the bottom plate. Repeat the test if the difference between values in the replicate determinations exceeds 1^{0}C.

<u>4.6 Ductility Test</u>

4.6.1 Background

The ductility of a paving asphalt cement is measured by the distance to which it will elongate before breaking when two ends of a briquette specimen are pulled apart at a certain

speed and temperature. The test procedure is specified by ASTM D113.

Though it is difficult to decide exactly which properties are measured by ductility test, a good correlation between ductility and shear susceptibility for various asphalts has been made. The ductility test also provide one measure of tensile properties of bituminous material and may be used to relate the ductility of asphalt cement to pavement performance.

4.6.2 Test equipment

A mold made of brass is used to prepare the test specimen. The testing machine is so constructed that the specimen will be continuously immersed in water while the two clips are pulled apart at an uniform speed without undue vibration.

A water bath is used to provide the specified test temperature. The specimen shall be supported on a perforated shelf not less than 5 cm from the bottom of the bath. The temperature is indicated by a thermometer.

4.6.3 Test procedure

Thoroughly coat the surface of a brass plate. Assemble the mold on a brass plate to prevent the material from sticking.

Carefully heat the sample until it become sufficiently fluid to pour. Pour it into the mold until it is more than level full. Let the mold containing the material cool to room temperature for a period of 30 to 40 minutes and then place it in the water bath maintained at the specific temperature of test for 30 minutes and trim off any excess with a warmed knife.

Place the brass plate and mold in the water bath for 85 to 95 minutes, and then remove the briquet from the plate. Detach the side pieces and immediately test the briquet.

Attach the rings at each end of the clips to the hooks in the testing machine, and pull the two clips apart at a uniform speed as specified until the briquet ruptures.

4.7 Chapter Summary

In this chapter, the background, equipment and procedures of the tests which are employed in this research were reviewed briefly. The purpose of this was to familiarize the reader with the the test results which will be presented in the following chapter.

Chapter 5

EFFECT OF PYROLYZED CARBON BLACK ON ASPHALT CEMENT

5.1 Introduction

This chapter presents the data collected from the laboratory tests. Three types of results are reported:

(1) Consistency index of original asphalt cements.

(2) Properties of asphalt modified by commercial carbon black.

(3) Effect of pyrolyzed carbon black on asphalt cements properties.

The equipment and procedures of the tests have been described in Chapter 4. Temperature susceptibility is analyzed based on the test results to show the effect of carbon black on asphalt cements.

5.2 Consistency of the Original Asphalt

Specific gravity tests, penetration tests at 77^0F and 59^0F, kinematic viscosity tests, ring and ball softening point tests and ductility tests were performed on the original asphalt. The results of the tests are tabulated in Table 5.1 and 5.2, and the test data are attached in Appendix A.

Linear increase of log penetration versus temperature for asphalt cement has been reported by Woods et al (1960). Penetration test results of AC10 and AC20 used in this study are plotted in Figure 5.1.

Table 5.1 Results of tests on AC10

Properties	Samples	Average	STD
Specific gravity, 77°F	3	1.028	---
Penetration 77°F, 100g, 5 sec.	3	101	0.50
Penetration 59°F, 100g, 5sec.	3	40	1.01
Kinematic viscosity, cSt	3	2894	1.44
Softening point , °F	4	123	0.43
Ductility, cm, 5cm/sec.	1	65*	---

(* Note: Run on the residue from the thin-film oven test.)

Table 5.2 Results of tests on AC20

Properties	Samples	Average	STD
Specific gravity, 77°F	3	1.033	---
Penetration 77°F, 100g, 5 sec.	3	65	0.70
Penetration 59°F, 100g, 5sec.	3	27	0.48
Kinematic viscosity, cSt	3	3955	2.08
Softening point , °F	4	126	0.19
Ductility, cm, 5cm/sec.	1	50*	---

(* Note: Run on the residue from the thin-film oven test.)

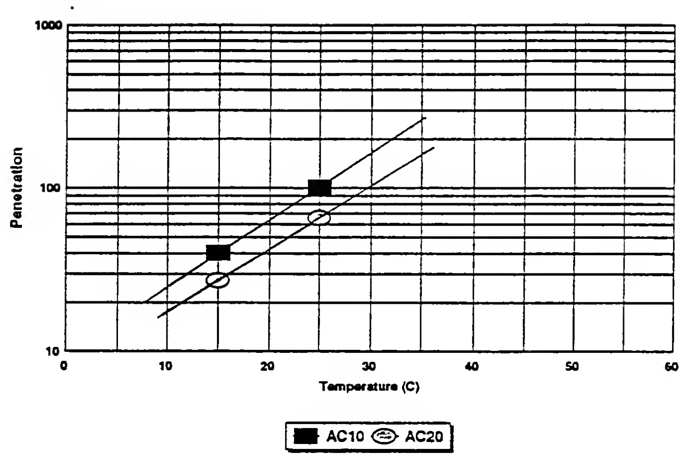


Figure 5.1 Relation of penetration and temperature

5.3 Effect of Commercial Carbon Black on Asphalt Cement

5.3.1 Test result

The commercial carbon black was used as an additive to AC10 and AC20 in this research for comparison. The percentages of the carbon black added are 5%, 10%, 15% and 20% of the total weight of the asphalt binder.

As is mentioned by Rostler et al(1977), the full dispersion of carbon black in asphalt cement is most important. The asphalt and carbon black samples were heated in the oven maintained at 250^{0}F in advance until the asphalt was fluid enough to mix. A manual controlled mixer with 200 revolutions/minute was provided to mix the asphalt and carbon

black. The commercial carbon black is a kind of black bulk powder. Attention must be paid to prevent the carbon black from polluting the working environment.

The settlement of carbon black in asphalt cement during the cooling period was found to cause large deviations in penetration results. Three practical methods were used in trying to solve the problem:

(1) The penetration box containing the specimen is immersed in ice water to reduce the time needed to cool the sample.

(2) The box is set into a machine which rotates at 60 revolutions/minute to prevent the uneven settlement of the carbon black to the bottom of the box.

(3) In order to observe the settlement of carbon black in asphalt cement, a penetration box, open at both ends is employed in the test so that the penetration can be performed on both sides of the box.

Due to the settlement of carbon black, it is practically impossible to obtain both the kinematic viscosity and absolute viscosity test results using conventional test methods. The data sheets of penetration test, softening point test and ductility test are attached in Appendix B. The results are plotted to show the properties of asphalt cement modified by carbon black.

Figure 5.2 and 5.3 show the penetration of AC10 and AC20 versus percentage of carbon black. From the Figures, at a testing temperature of 77°F, the penetration of AC10 and AC20 decreases steadily from 101 to 68 and 65 to 48, respectively, when the percentage of the carbon black added increases from 0% to 20%; at 59°F, the penetration decreases from 40 to 31 and 27 to 19, respectively, with the increase of carbon black added.

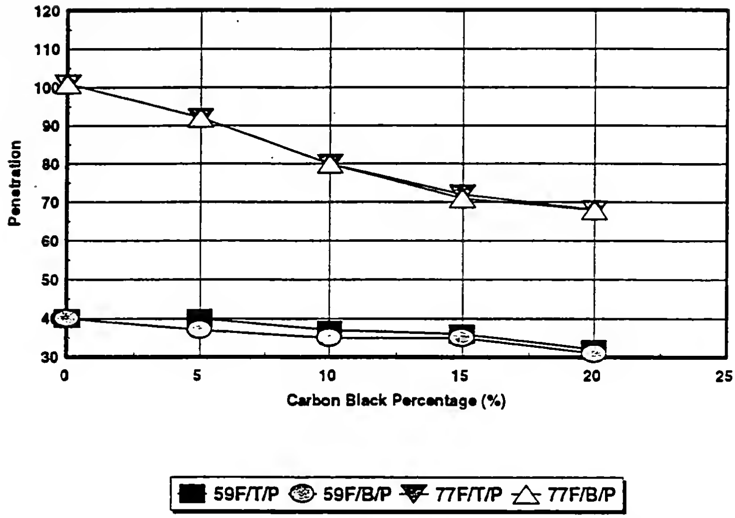


Figure 5.2 Penetration of AC10 modified by carbon black

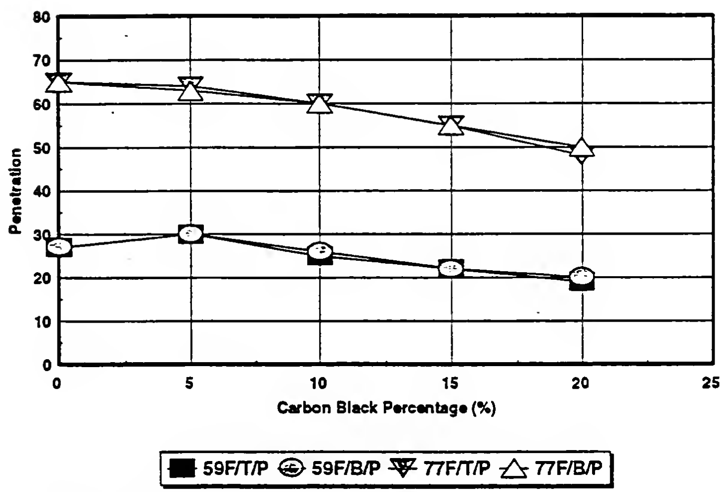


Figure 5.3 Penetration of AC20 modified by carbon black

Figure 5.4 presents the softening point test results. The softening point of AC10 increases from 123⁰F to 137⁰F when the carbon black percentage increases from 0% to 20%; the softening point of AC20 increases from 126⁰F to 136 F when the carbon black percentage increases.

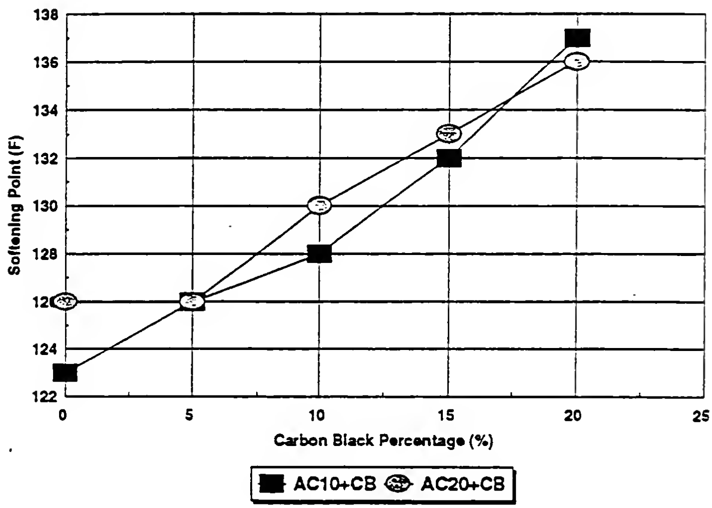


Figure 5.4 Softening points of AC10 and AC20 modified by carbon black

5.3.2 Temperature susceptibility

Since it is a thermoplastic material, the consistency of asphalt changes with temperature. Temperature susceptibility is the rate at which the consistency of an asphalt

cement changes with a change in temperature, and is a very important property of asphalt cement. There are currently three different approaches for determining temperature susceptibility, namely, penetration index, penetration-viscosity number and viscosity-temperature susceptibility. Because the viscosity tests of the asphalt cement modified by carbon black were practically impossible to perform due to the settlement of carbon black, the penetration index is used as a measure of temperature susceptibility in this research.

Penetration index was first proposed by Pfeiffer and Van Doormaal (1950). It was assumed that the penetration of an asphalt cement at its softening point is 800 and the plot of logarithm of penetration against temperature normally gives a straight line. The slope of the line is calculated as

$$A=\frac{\log P_1-\log P_2}{T_1-T_2}$$

and penetration index (PI) is given by:

$$P.I=\frac{20-500A}{1+50A}$$

In the above equations, T_1, T_2 are different temperatures, P_1, P_2 are penetrations at T_1 and T_2 respectively.

The lower the penetration index values, the higher its temperature susceptibility. Most paving asphalt cements have a penetration index between ±2.0. When penetration index is less than -2.0, then the asphalt cement is highly temperature susceptible, usually exhibits

brittleness at low temperature and is very prone to transverse cracking in cold regions.

Figure 5.5 shows the penetration index (PI) of AC10 and AC20 versus percentage of carbon black added. For AC10, PI tends to increases slightly from 0.0 to about 1.8 and then drops to 1.2. For AC20, penetration index does not show much increase. The value increases from 0.38 to about 1.4 and then drops to 0.0.

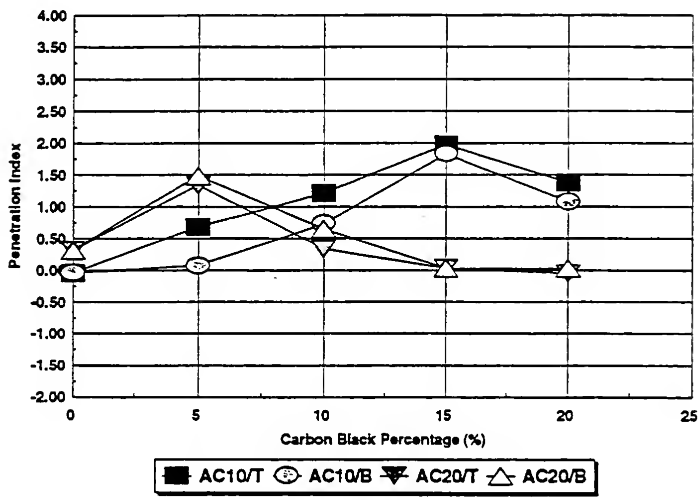


Figure 5.5 Temperature susceptibility of AC10 and AC20 modified by carbon black

Ductility test results for AC10 and AC20 plus carbon black are tabulated in Table 5.3. The values of ductility obviously decrease due to the inclusion of carbon black.

Table 5.3 Ductility of AC10 and AC20 modified by carbon black

Percent Carbon Black	AC10+CB	AC20+CB
0%	60	40
5%	90	100
10%	34	21
15%	17	14
20%	11	14

5.4 Effect of Pyrolyzed Carbon Black on Asphalt Cement

5.4.1 Test result

The same tests procedures were used to investigate the effect of pyrolyzed carbon black on asphalt cements. The results demonstrate some special phenomena due to the unique characteristics of the pyrolyzed carbon black. The density of the pyrolyzed carbon black is larger than that of commercial carbon black and thus the settlement problem is more serious.

Figure 5.6 and 5.7 illustrate the penetrations at 59^0F and 77^0F on both ends of the penetration box for AC10 and AC20. The trends are essentially the same as those for commercial carbon black on asphalt cements; the penetration at either temperature decreases steadily when the percentage of carbon black added increases. The most obvious difference is that the difference of penetration between the top and bottom of the box is larger.

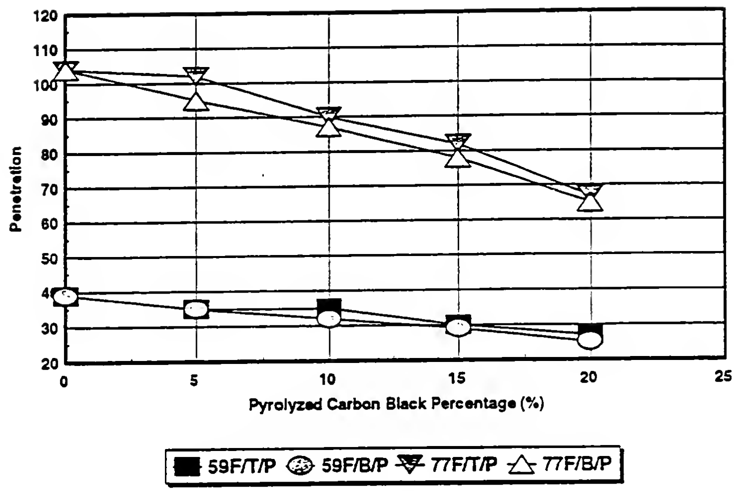


Figure 5.6 Penetration of AC10 modified by pyrolyzed carbon black

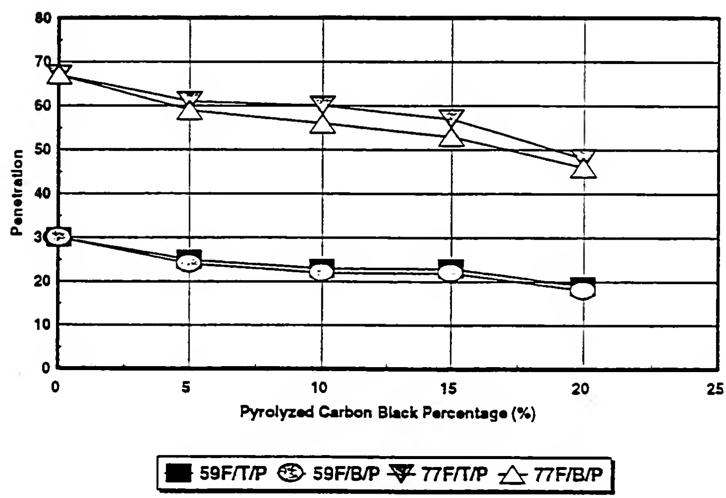


Figure 5.7 Penetration of AC20 modified by pyrolyzed carbon black

Figure 5.8 shows the softening point of AC10 and AC20 against the percentage of pyrolyzed carbon black added. The softening point of AC10 increases from 123°F to 131°F, and increases from 126°F to 132°F for AC20. The data sheets of all the tests on pyrolyzed carbon black modified asphalt cements are attached in Appendix C.

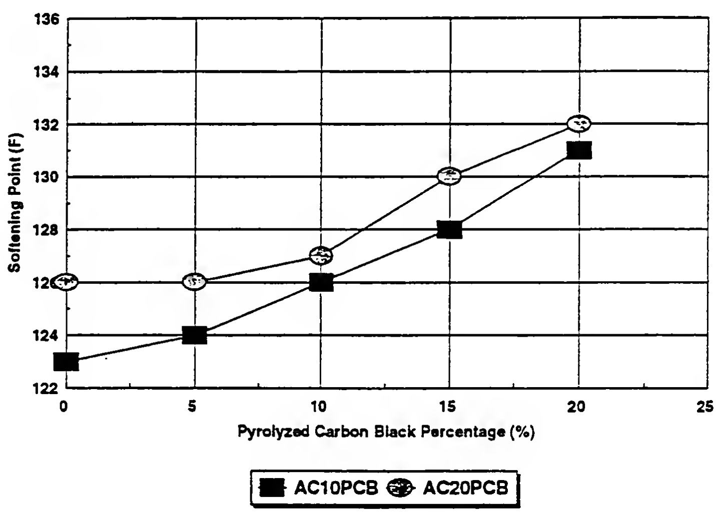


Figure 5.8 Softening points of AC10 and AC20 modified by pyrolyzed carbon black

5.4.2 Temperature susceptibility

As shown in Figure 5.9, the penetration index of AC10 modified by pyrolyzed carbon black is approximately a straight line with a slight increase. The plot also indicates a decrease of penetration index. The difference between the penetration index obtained form the top and bottom of the penetration box is obviously larger.

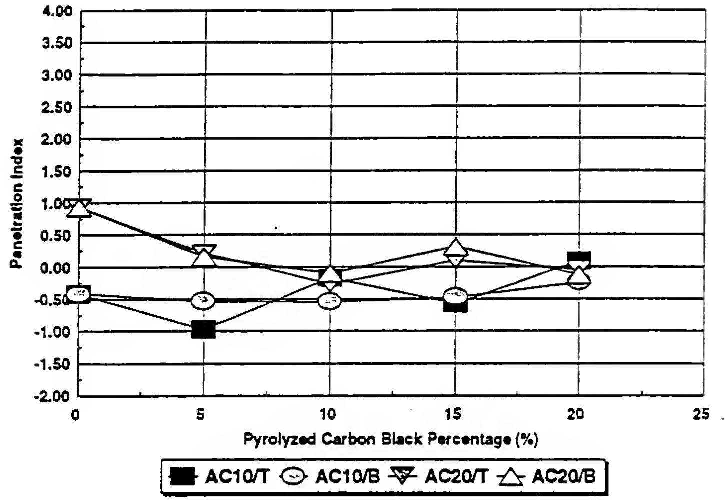


Figure 5.9 Temperature susceptibility ofAC10 and AC20 modified by pyrolyzed carbon black

Table 5.4 is the result of ductility tests. The same trend as that of the asphalt cements modified by the carbon black is observed.

Table 5.4 Ductility of AC10 and AC20 modified by pyrolyzed carbon black

Percent Pyrolyzed Carbon Black	AC10+PCB	AC20+PCB
0%	60	40
5%	95	100
10%	30	28
15%	15	20
20%	11	18.5

5.5 Aging of Asphalt Cement with Carbon Black

5.5.1 Background

Asphalt cements will undergo substantial aging during the service life of hot mix asphalt pavement. There are two kinds of aging. The first one is called short-term aging which occurs when the asphalt cements are mixed with hot mineral aggregate in a hot mix asphalt facility. Another kind of aging is long-term aging which will continue through the life of pavement. Long-term aging is due to environmental factors, such as changes of weather.

Chemically, the following six factors contribute to the age hardening of asphalt cements [Robert et al, 1991].

(1) Oxidation---Reaction of oxygen with asphalt cement.

(2) Volatilization---The evaporation of the lighter constitutes from the asphalt cement and is primarily a function of temperature.

(3) Polymerization---Combining of like molecules to form larger a molecule causing a progressive hardening.

(4) Thixotropy--Progressive hardening due to the formation of a structure within the asphalt cement over a period of time.

(5) Syneresis---An exudation reaction in which the thin oily liquids are exuded to the surface of the asphalt cement film.

(6) Separation---The removal of the oily constitutes, resins or asphaltenes from the asphalt cement.

5.5.2 Aging test results

The aging of asphalt was simulated by pouring the mixture of asphalt and carbon into a flat pan up to about 0.5 cm thickness and heating the sample in an oven maintained at 275^{0}F for exactly 16 hours. The penetration test, softening point test and ductility test samples were prepared using the material after aging.

Figure 5.10 to Figure 5.13 are the results of penetration tests on aged asphalt cements mixed with commercial carbon black. The smaller metallic penetration can with one open end is used for two reasons. Firstly, the aged material is insufficient to make specimens using the larger plastic can; Secondarily, there is not a significant difference between the penetration on the top and on the bottom of the plastic can.

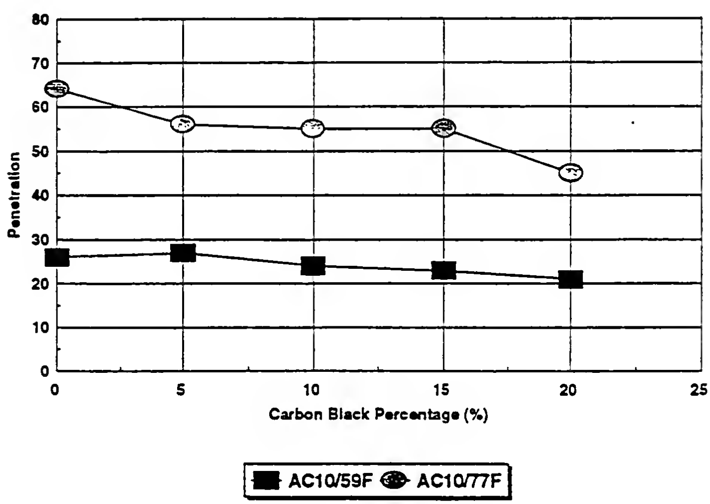


Figure 5.10 Penetration of aged AC10 modified by carbon black

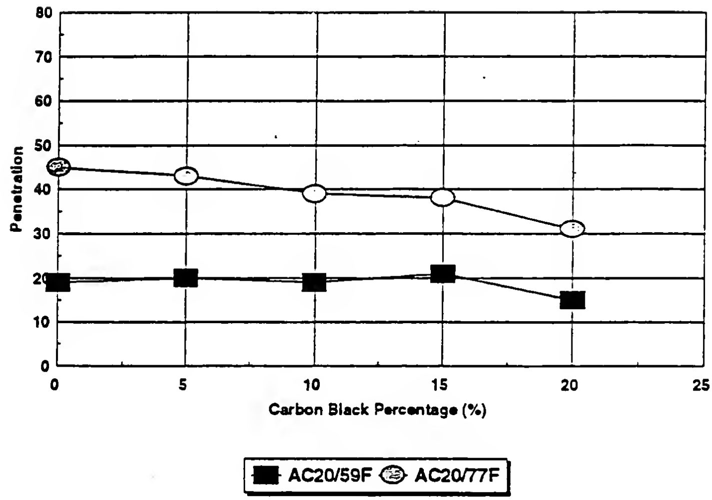


Figure 5.11 Penetration of aged AC20 modified by carbon black

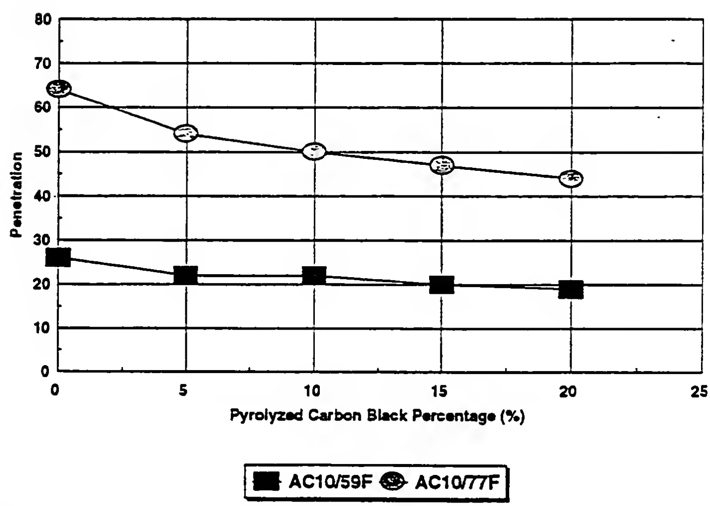


Figure 5.12 Penetration of aged AC10 modified by pyrolyzed carbon black

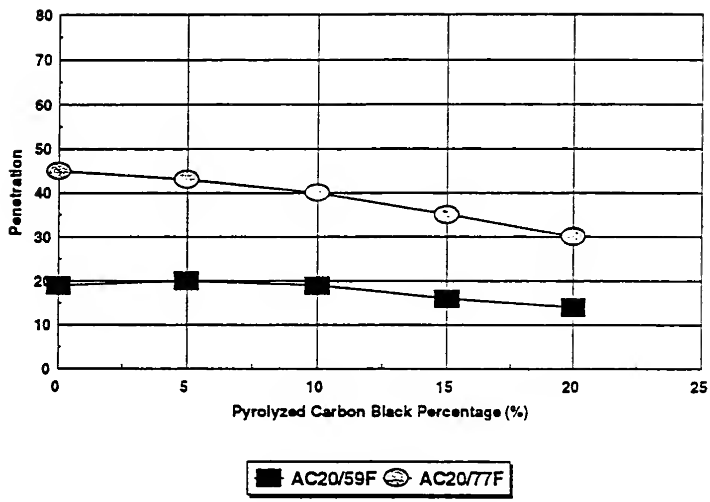


Figure 5.13 Penetration of aged AC20 modified by pyrolyzed carbon black

The extent of age hardening can be qualified in terms of percent retained penetration

$$Retained\ Penetration = \frac{Penetration\ of\ aged\ asphalt}{Penetration\ of\ original\ asphalt} \times 100\%$$

The retained penetrations of AC10 and AC20 modified by carbon black are summarized in Table 5.3 to 5.6.

Table 5.3 Retained penetrations of asphalt cements modified by commercial carbon black (77°F)

Percent	AC10+ Carbon Black			AC20+ Carbon Black		
	Original	Aged	Retained	Original	Aged	Retained
0%	101	64	63%	65	45	69%
5%	92	56	61%	60	43	72%
10%	80	55	69%	60	39	65%
15%	72	55	76%	55	38	69%
20%	68	45	66%	49	31	63%

Table 5.4 Retained penetrations of asphalt cements modified by commercial carbon black (59°F)

Percent	AC10+ Carbon Black			AC20+ Carbon Black		
	Original	Aged	Retained	Original	Aged	Retained
0%	40	26	65%	27	19	70%
5%	38	27	71%	25	20	80%
10%	36	24	67%	25	19	86%
15%	35	23	66%	22	21	95%
20%	32	21	66%	19	15	79%

Table 5.5 Retained penetrations of asphalt cements modified bypyrolyzed carbon black (77°F)

Percent	AC10+ Pyrolyzed Carbon Black			AC20+ Pyrolyzed Carbon Black		
	Original	Aged	Retained	Original	Aged	Retained
0%	104	64	62%	67	45	67%
5%	98	54	55%	60	43	72%
10%	90	50	56%	58	40	69%
15%	80	47	59%	55	35	64%
20%	66	44	67%	47	30	64%

Table 5.6 Retained penetrations of asphalt cements modified by pyrolyzed carbon black (59°F)

Percent	AC10+ Pyrolyzed Carbon Black			AC20+ Pyrolyzed Carbon Black		
	Original	Aged	Retained	Original	Aged	Retained
0%	39	26	67%	30	19	63%
5%	35	22	63%	24	20	83%
10%	32	22	69%	23	19	83%
15%	30	20	67%	22	16	73%
20%	26	19	73%	19	14	74%

Figure 5.14 and Figure 5.15 illustrate the softening point against the percentage of carbon black and pyrolyzed carbon black added, respectively. It can be seen that the softening point increases as the percentage of carbon increases. The softening point of asphalt cements modified by pyrolyzed carbon black is generally higher than that of asphalt cements modified by commercial carbon black of the same addition percentage.

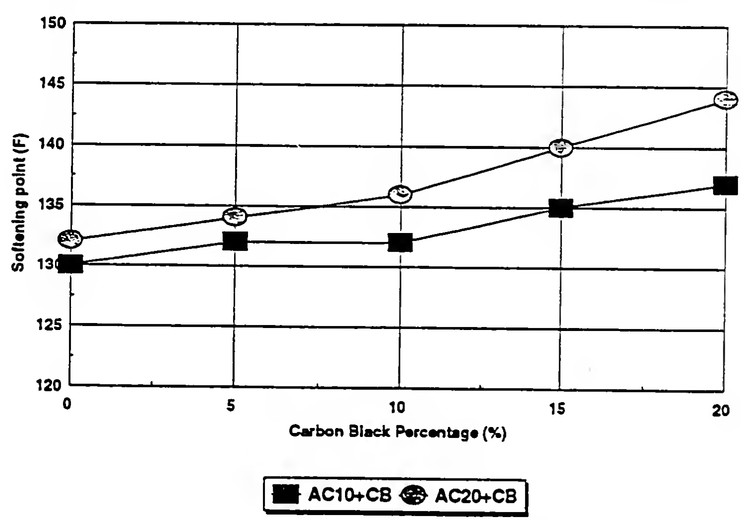


Figure 5.14 softening points of aged AC10 and AC20 modified by carbon black

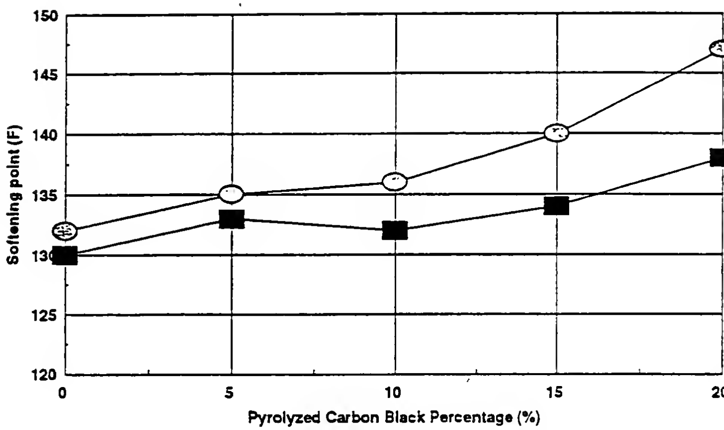


Figure 5.15 Softening points of aged AC10 and AC20 modified by pyrolyzed carbon black

Figure 5.16 and 5.17 show the values of penetration index with respect to carbon black quantity. Penetration index for asphalt cements with commercial carbon black tends to increase. The range of penetration index is between 0.0 and 1.5. Penetration index for asphalt cements with pyrolyzed carbon black remains practically unchanged with a range between 0.0 and 1.0.

Table 5.9 and Table 5.10 are the results of ductility tests. The ductility of the asphalt cements and 0%, 5% carbon is much larger than the specification requirement, and it drops when the percentage of carbon increases.

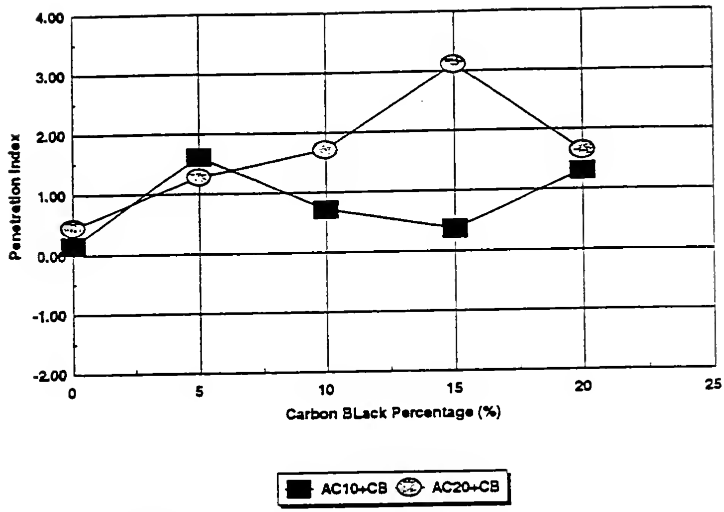


Figure 5.16 Temperature susceptibility of aged AC10 and AC20 modified by carbon black

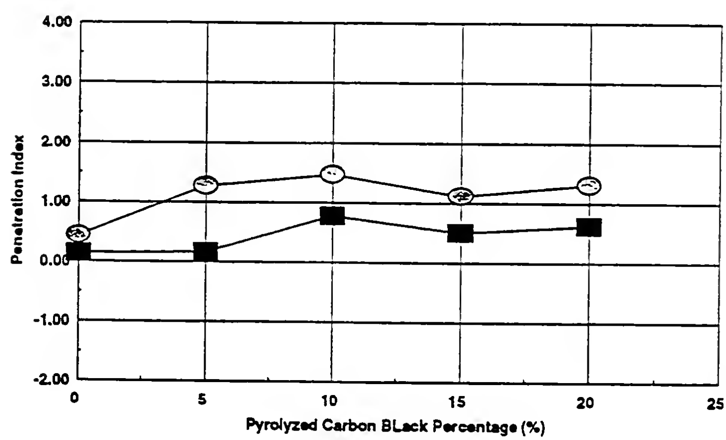


Figure 5.17 Temperature susceptibility of aged AC10 and AC20 modified by pyrolyzed carbon black

Table 5.9 Ductility of aged AC10 and AC20 modified by carbon black

Percent of Carbon Black	AC10+CB	AC20+CB
0%	65	50
5%	100	98
10%	81	99
15%	60	52
20%	39	32

Table 5.10 Ductility of aged AC10 and AC20 modified by pyrolyzed carbon black

Percent of Pyrolyzed Carbon Black	AC10+CB	AC20+CB
0%	65	50
5%	110	110
10%	77	38
15%	46	29
20%	42	11

5.6 Regression Analysis

Because of the insufficient dispersion and the separation of carbon black and pyrolyzed carbon black in the mixtures, the testing results presented in the above section indicate some deviation and inconsistency. Considering this, the regression based on the raw data should be performed.

5.6.1 Penetration

Previous research indicated a linear relationship of the penetration of asphalt binders against carbon black percentage [Rostler et al, 1977]. Figure 5.18 and Figure 5.19 illustrate the regression curves of penetration of AC10 at 77°F and 59 F against the percentage of carbon black and pyrolyzed carbon black added. The difference between regression and raw data is about 0-5% of the test results.

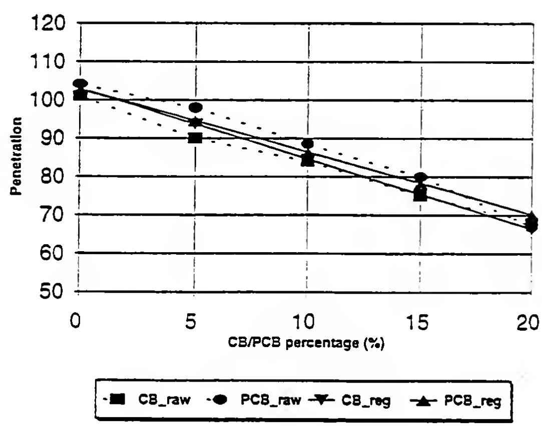


Figure 5.18 Regression of penetration of AC10+CB/PCB at 77 °F

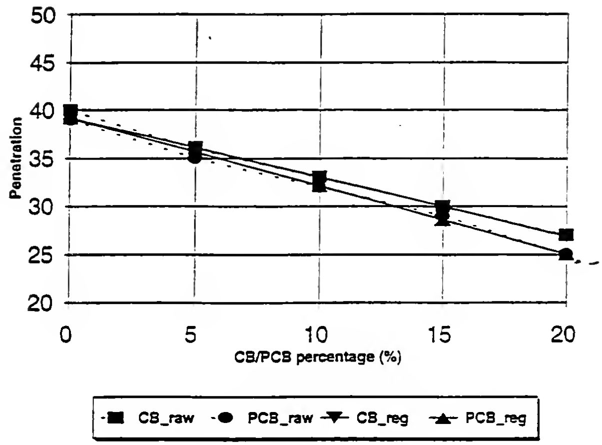


Figure 5.19 Regression of penetration of AC10+CB/PCB at 59 °F

5.6.2 Softening point

Many experiments showed a parabolic relation between the softening point of asphalt and carbon black. As such, the regression curves in Figure 5.20 for AC10 modified by carbon black and pyrolyzed carbon black indicates a small deviation of test results. The raw data fit very well with the parabolic regression data.

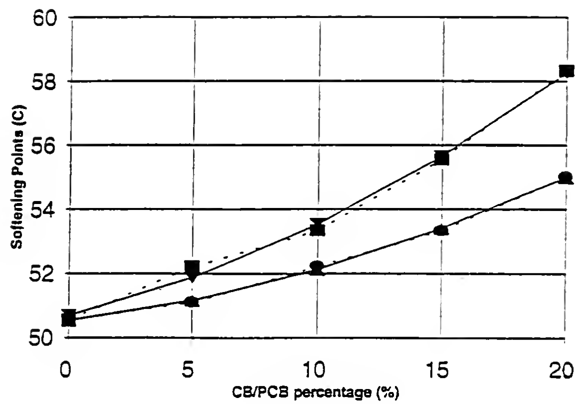


Figure 5.20 Regression of softening point of AC10+CB/PCB

5.6.3 Binder stiffness modulus

Asphalt cement is inherently a visco-elastic material. The deformation potential of asphalt binder at certain temperature can be evaluated using binder stiffness, which is analogous to elastic modulus. The difference lies in that the binder stiffness of asphalt cement is a function of temperature.

A nomograph which yields the behavioral properties of bituminous binders was proposed by Van der Poel (1954) to find out the binder stiffness graphically. With this

nomograph, the binder stiffness S_b may be established through a knowledge of the binder penetration, binder softening point, penetration index, frequency of loading and temperature. A regression equation based on the Van der Poel nomograph was provided by Ullitz (1979) for binder stiffness as:

$$S_b(MPa)=1.157\times10^{-7}t^{-0.368}e^{-PI}(T_{RB}-T)^5$$

where,

	S_b	=binder stiffness(MPa)
	t	=the time of loading (Second)
	P.I	=the penetration index
	T_{rb}	=the ASTM D36 ring and ball softening point (°C)
	T	=the ambient, or material test temperature (°C)

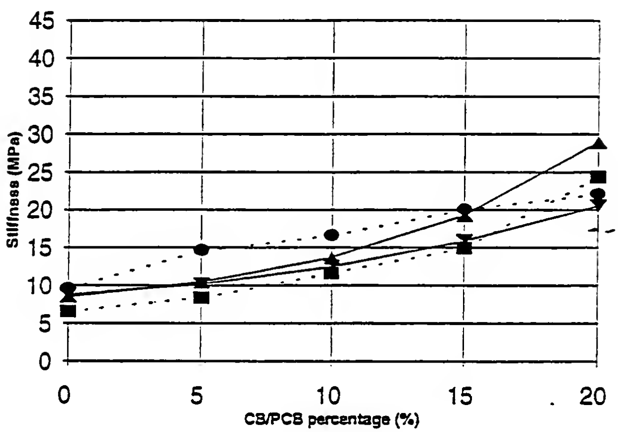


Figure 5.21 Binder stiffness of AC10+CB/PCB

Figure 5.21 shows the raw and regression curves of binder stiffness of AC10 modified by carbon black and pyrolyzed carbon black. The Figure indicates:

(1) Binder stiffness increases with the increase of carbon black or pyrolyzed carbon black percentage in asphalt binder.

(2) The binder stiffness of AC10 modified by pyrolyzed carbon black is generally larger than that modified by carbon black at the same testing temperature and additive percentage.

Similarly, Figure 5.22 and Figure 5.23 show the regression of penetration of AC20 modified by carbon black and pyrolyzed carbon black, which also indicates a good consistency between raw data and data from regression. Figure 5.24 shows the regression of softening point of AC20 modified by carbon black and pyrolyzed carbon black; Figure 5.25 shows the binder stiffness of AC20 and carbon black or pyrolyzed carbon black mixtures.

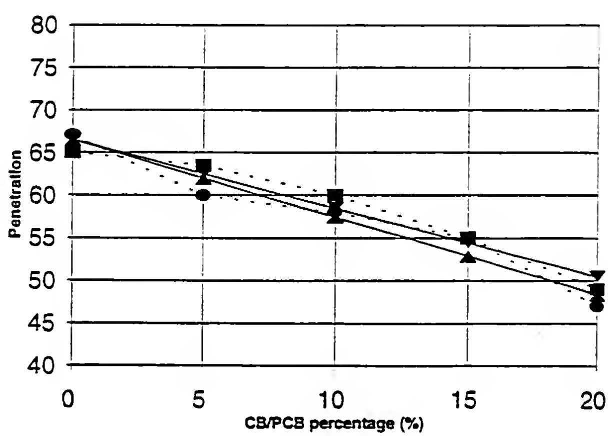


Figure 5.22 Regression of penetration of AC20+CB/PCB at 77°F

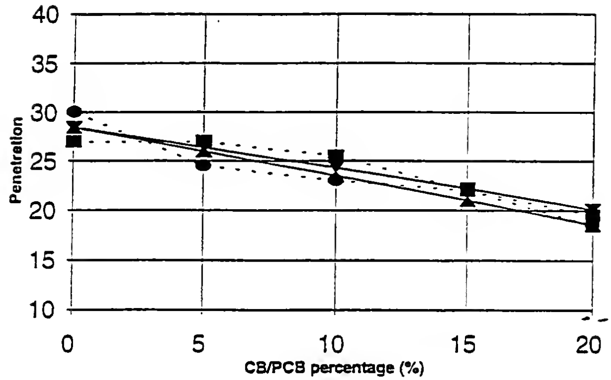


Figure 5.23 Regression of penetration of AC20+CB/PCB at 59°F

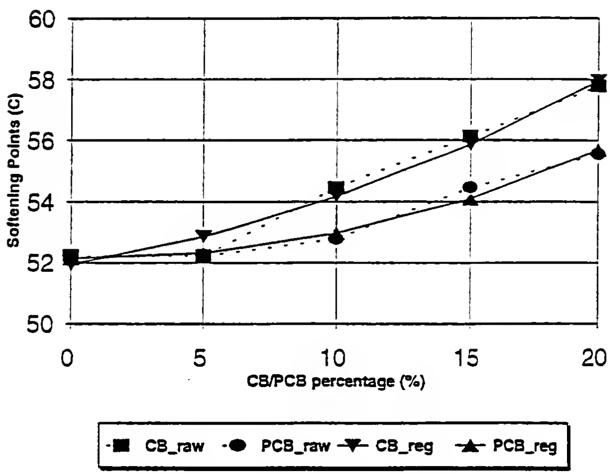


Figure 5.24 Regression of softening point of AC20+CB/PCB

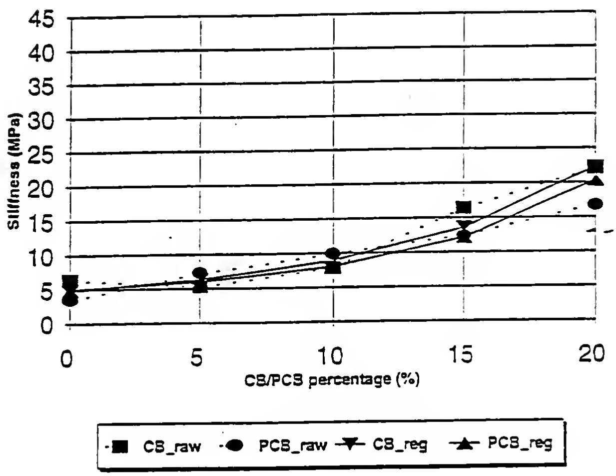


Figure 5.25 Binder stiffness of AC20+CB/PCB

For aged asphalt binder, the similar sets of regression are performed, and the results come out to be less consistent than the unaged materials due to the following reasons:

(1) The degree of aging is not exactly the same for each test sample. Different extents of aging may have different test results.

(2) Separation of carbon black and pyrolyzed carbon black during the aging process is one of the causes of result inconsistency.

(3) Less sample available for testing also causes some deviation.

Figure 5.26 through Figure 5.33 illustrate the regression of test results from aged AC10 and AC20 modified by carbon black and pyrolyzed carbon black. As can be seen, the difference between test data and regression data is over 10% at some data points, and the increase of binder stiffness with the increase of additive percentage is not so significant.

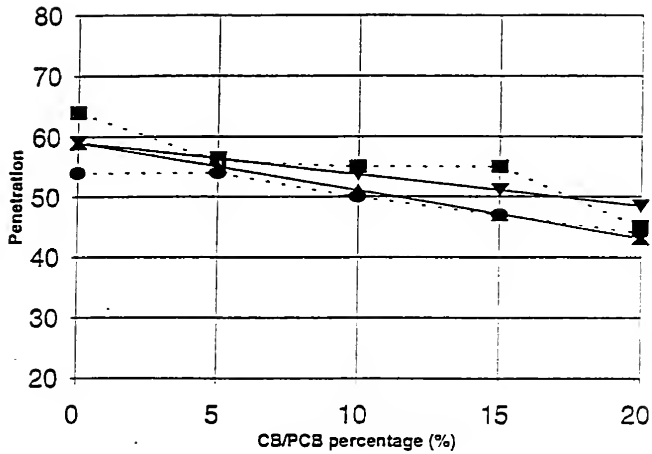


Figure 5.26 Regression of penetration of AC10+CB/PCB at 77°F (Aged)

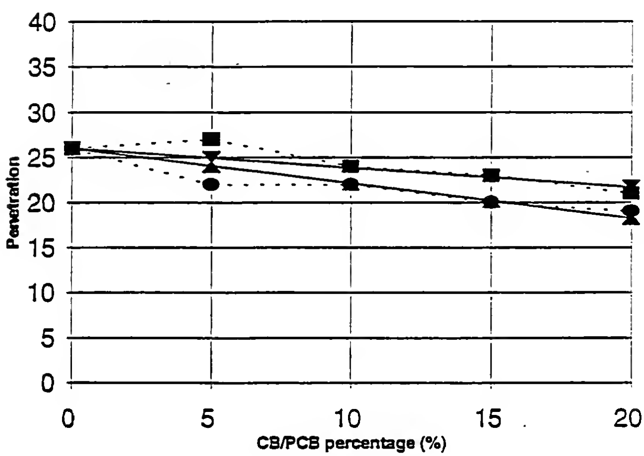


Figure 5.27 Regression of penetration of AC10+CB/PCB at 59°F (Aged)

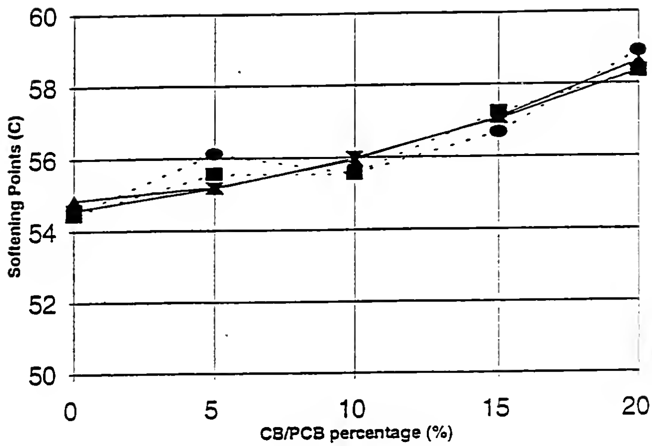


Figure 5.28 Regression of softening point of AC10+CB/PCB (Aged)

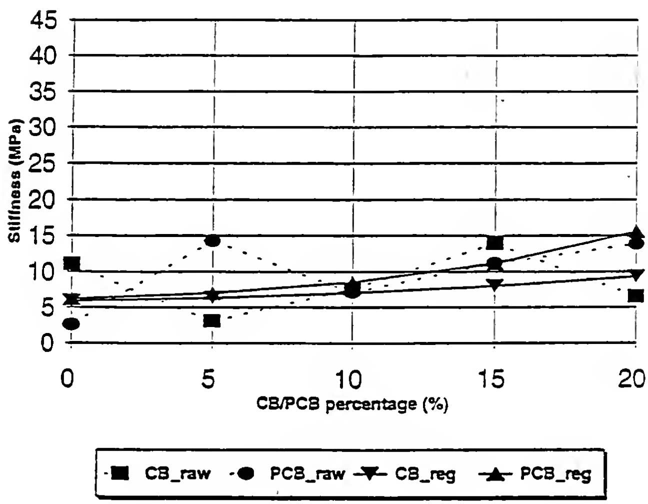


Figure 5.29 Binder stiffness AC10+CB/PCB (Aged)

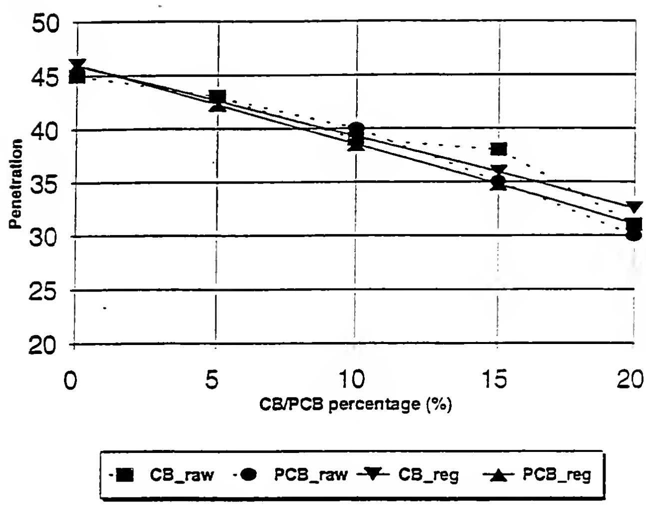


Figure 5.30 Regression of penetration of AC20+CB/PCB at 77°F (Aged)

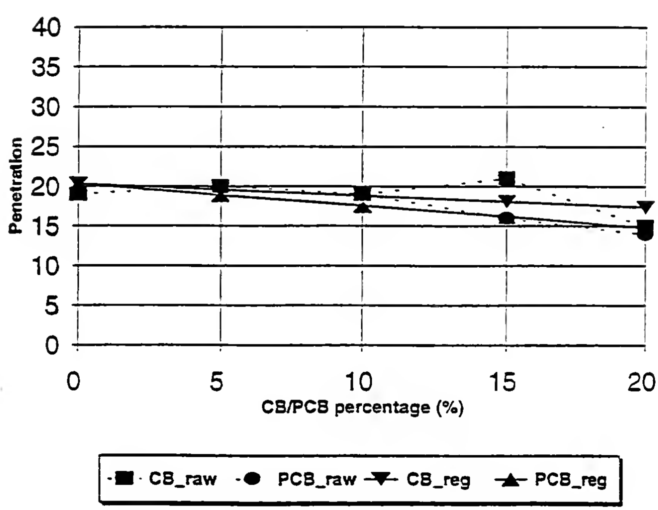


Figure 5.31 Regression of penetration of AC20+CB/PCB at 59°F (Aged)

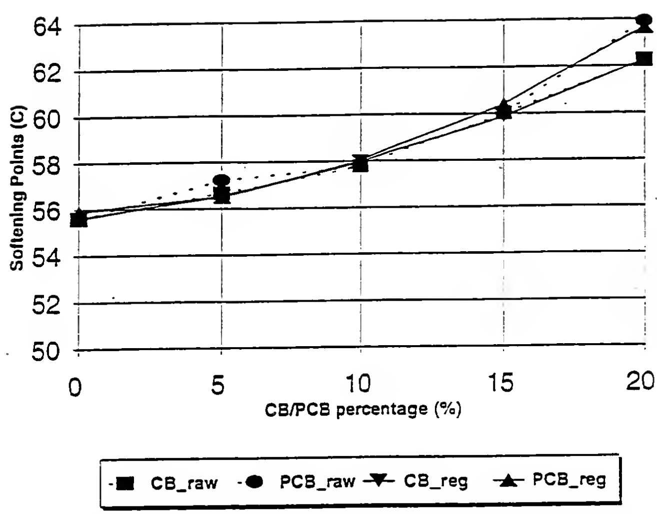


Figure 5.32 Regression of softening point of AC20+CB/PCB (Aged)

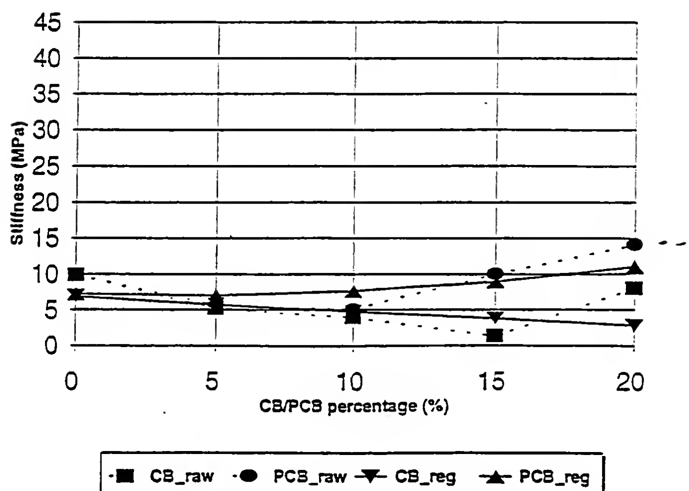


Figure 5.33 Binder stiffness of AC20+CB/PCB (Aged)

5.7 Chapter Summary

The consistency test results of ariginal pure asphalt cements are presented in this chapter. The effect of carbon black as well as pyrolyzed carbon black on aphalt cements are discussed based on the data resulting from the laboratory tests. The main focus of the chapter is on the property changes of asphalt cements due to the inclusion of pyrolyzed carbon black. The results obtained from the regression analysis provide a good reference for making decisions whether the pyrolyzed carbon black is recommended for use in asphalt pavements.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This is the second in a three-part reporting of research on the topic. The reader is also referred to Park (1995) for relevant conclusion and recommendations.

The use of pyrolyzed carbon black as an additive of hot mix asphalt cements produces the following benefits:

(1) Disposal of scrap automobile tires. This may be one of the most desirable techniques from an economic and environmental standpoint.

(2) The inclusion of pyrolyzed carbon black will improve the temperature susceptibility of asphalt cements, and hence the service life of hot mix asphalt pavements.

The test results presented in Chapter 5 indicate that:

(a) Penetrations of the asphalt cements modified both by carbon black and pyrolyzed carbon black decrease steadily. The higher the test temperature, the larger the penetration value for the same percentage of carbon black added.

(b) Softening point of the asphalt cements mixed with carbon black or pyrolyzed carbon black increases when the quantity of carbon black added increases. The later one has a higher softening point than the former one.

(c) Though the results may not indicate much improvement of temperature susceptibility, the addition of pyrolyzed carbon black will not have adverse effect on asphalt properties.

(d) The pyrolyzed carbon black use has a cost advantage over that of commercial carbon black. The objective of the study of this part is to demonstrate the property changes due to the pyrolyzed carbon black. For the cost calculation, the readers can refer to Park (1995).

6.2 Recommendation

Because of the characteristics of pyrolyzed carbon black, several problems become evident during this research. It is advisable to include the following recommendations.

(1) The settlement or separation of carbon black or pyrolyzed carbon black in asphalt is quite common. Sufficient stirring or mixing must be provided in the laboratory.

(2) It is difficult to mix either the carbon black or pyrolyzed carbon black percentage beyond 20%. Consequently, lower percentages of carbon, ranging from 10% to 15% are recommended, in order to obtain homogenious mixtures. Field mixing requires further study.

(3) Handling of carbon black requires special and careful controlled procedures.

(4) Although the quality control on the pyrolyzed carbon black test road (SR46) was very poor, a preliminary condition survey is reported in Appendix B. Further condition surveys to determine the indicated benefits should be undertaken and reported.

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APPENDIX A: Experimental Data

a. Specific Gravity of Asphalt Cements *

1. Asphalt cement: AC10

The density of water at 25°C is 0.9971g/cm³ Unit: g

Test Index	Sample 1	Sample 2	Sample 3
Wt. of dry pycnometer	32.08	29.33	28.73
Wt. of water+pycnometer	57.04	55.45	55.10
Wt. of asphalt+pycnometer	45.98	44.78	43.34
Wt of water+asphalt+pycn.	57.42	55.88	55.50
Specific gravity	1.0281	1.0286	1.0281

2. Asphalt cement: AC20

The density of water at 25°C is 0.9971g/cm³ Unit: g

Test Index	Sample 1	Sample 2	Sample 3
Wt. of dry pycnometer	29.35	30.28	29.83
Wt. of water+pycnometer	55.11	54.41	54.98
Wt. of asphalt+pycnometer	45.73	44.74	46.47
Wt of water+asphalt+pycn.	55.62	54.88	55.51
Specific gravity	1.0321	1.0335	1.0329

[* All the tests included in this report were performed in the material laboratory, Division of Research, Indiana Department of Transportation.]

b.1 Penetration Test on Asphalt Modified by Commercial Carbon Black

Material: AC10 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 0%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	39	41	40	41		
Sample 2	38	40.5	40	41		
Sample 3						
Maximum: 41	**Minimum:** 38		**Average:** 41		**Std. :** 1.01	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC10 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 0%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	101	101	101	100		
Sample 2	102	101	101	101		
Sample 3						
Maximum: 102	**Minimum:** 100		**Average:** 101		**Std. :** 0.50	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC10 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 5%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	39	42	40	39	40	40
Sample 2	43	39	39	44	38	42
Sample 3	37	37	39	39	38.5	38
Maximum: 44	**Minimum:** 37		**Average:** 40		**Std. :** 1.90	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	38	38	40	38	37	38
Sample 2	36.5	36.5	38	36	37	37
Sample 3	37	36	37	38	36	36
Maximum: 40	**Minimun:** 36		**Average:** 37		**Std. :** 1.02	

Material: AC10 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 5%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	92	92.5	93	92.5		
Sample 2	91	92.5	92	92		
Sample 3	89	89	91.5	91		
Maximum: 93	**Minimum:** 89		**Average:** 91.5		**Std. :** 1.26	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	90	91	93	93		
Sample 2	93	91	90	93		
Sample 3	92	91.5	92	93		
Maximum: 93	**Minimun:** 90		**Average:** 92		**Std. :** 1.12	

Material: AC10 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 10%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	38	35.5	36.5	36	35.5	36
Sample 2	38	37.5	38	37	37	38
Sample 3	36.5	36	36.5	36	36.5	36.5
Maximum: 38	**Minimum:** 35.5		**Average:** 37		**Std. :** 0.84	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	34	34	34.5	33.5	32 5	33
Sample 2	36	35	35	36	35	34.5
Sample 3	35.5	38	35.5	36	36.5	39
Maximum: 39	**Minimun:** 32.5		**Average:** 35		**Std. :** 1.48	

Material: AC10 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 10%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	82	79	80	81		
Sample 2	80	80	80	81		
Sample 3	78.5	79	80	81		
Maximum: 82	**Minimum:** 78.5		**Average:** 80		**Std. :** 0.96	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	80	79.5	78	82		
Sample 2	81	79.5	79.5	80		
Sample 3	82	80	81	81.5		
Maximum: 82	**Minimun:** 78		**Average:** 80		**Std. :** 1.14	

Material: AC10 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	33.5	35	36	36	36	37
Sample 2	35.5	36	36	36	36	36
Sample 3	35	36	36	37	36	35
Maximum: 37	**Minimum:** 33.5		**Average:** 36		**Std.:** 0.79	
Bottom of Box	1	2	3	4	5	6
Sample 1	38	35	36.5	36	37	37
Sample 2	34	33	33	34	33.5	34
Sample 3	35.5	37	34	35.5	33	35
Maximum: 38	**Minimun:** 33		**Average:** 35		**Std.:** 1.54	

Material: AC10 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	73	72	74	71		
Sample 2	72.5	74	71	74		
Sample 3	71	72	71	72.5		
Maximum: 74	**Minimum:** 71		**Average:** 72		**Std.:** 1.16	
Bottom of Box	1	2	3	4	5	6
Sample 1	69	70	71	70		
Sample 2	74	71	69.5	70		
Sample 3	71	70.5	69.5	70.5		
Maximum: 74	**Minimun:** 69		**Average:** 71		**Std.:** 1.22	

Material: AC10 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 20%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	33.5	30	32	31	32	30
Sample 2	30	31	32	29	31	32
Sample 3	31	30.5	30	32	31	31
Maximum: 33.5	**Minimum:** 29		**Average:** 32		**Std. :** 1.04	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	32	32	32	32	31	32
Sample 2	32	30.5	32	30	33	32
Sample 3	32	31	32	32	32	32
Maximum: 33	**Minimun:** 30		**Average:** 32		**Std. :** 0.67	

Material: AC10 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 20%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	68	68.5	68	68		
Sample 2	67	68	67	68		
Sample 3	67	68	66	67		
Maximum: 68.5	**Minimum:** 66		**Average:** 68		**Std. :** 0.69	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	69	68	69	68		
Sample 2	68	67.5	68	69		
Sample 3	67.5	66	68	68		
Maximum: 69	**Minimun:** 66		**Average:** 68		**Std. :** 0.79	

Material: AC20 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 0%

Top of Box	1	2	3	4	5	6
Sample 1	27	27	28	28		
Sample 2	27	27	28	27		
Sample 3						
Maximum: 28	**Minimum:** 27		**Average:** 27		**Std. :** 0.48	
Bottom of Box	1	2	3	4	5	6
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC20 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 0%

Top of Box	1	2	3	4	5	6
Sample 1	65	66	65	66		
Sample 2	66	65	65	65		
Sample 3						
Maximum: 66	**Minimum:** 65		**Average:** 65		**Std. :** 0.48	
Bottom of Box	1	2	3	4	5	6
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC20 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 5%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	26	22	23	22	20	24
Sample 2	28	26	24	25	24	28
Sample 3	23	21	26	24	26	25
Maximum: 28	**Minimum:** 20		**Average:** 24		**Std. :** 2.16	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	29	24	24	23	24	24
Sample 2	26	23	23	25	25	23
Sample 3	24	24	24	24	23	24
Maximum: 29	**Minimun:** 23		**Average:** 24		**Std. :** 1.61	

Material: AC20 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 5%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	55	61	63	59	58	60
Sample 2	60	64	61	64	58	64
Sample 3	61	63	63	61	61	62
Maximum: 64	**Minimum:** 55		**Average:** 61		**Std. :** 2.36	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	56	60	59	60	59	60
Sample 2	56	55	60	57	56	57
Sample 3	62	62	60	59	61	59
Maximum: 62	**Minimun:** 55		**Average:** 59		**Std. :** 2.07	

Material: AC20 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 10%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	26	25	27	25.5		
Sample 2	26.5	25	26	25		
Sample 3	24	25	25	24		
Maximum: 27	**Minimum:** 24		**Average:** 25		**Std. :** 0.87	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	25	27	26	27		
Sample 2	27	26.5	26.5	26		
Sample 3	26.5	25	25	26		
Maximum: 27	**Minimun:** 25		**Average:** 26		**Std. :** 0.74	

Material: AC20 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 10%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	58.5	60	60	60.5	59.5	59.5
Sample 2	60	60	60.5	59.5	61.5	60
Sample 3	58.5	58	59.5	61	61	61
Maximum: 61.5	**Minimum:** 58		**Average:** 60		**Std. :** 0.92	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	61.5	58.5	61	58.5	58.5	60
Sample 2	61	61	60.5	60	59.5	60
Sample 3	58.5	61	58.5	62.5	58.5	60.5
Maximum: 62	**Minimun:** 58.5		**Average:** 60		**Std. :** 1.17	

Material: AC20 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	22	21	21	21		
Sample 2	21	23	22	21		
Sample 3	21	22	21	22		
Maximum: 23	**Minimum:** 21		**Average:** 22		**Std. :** 0.65	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	22	23	23	22		
Sample 2	22	22.5	22.5	23		
Sample 3	21.5	22	21.5	22		
Maximum: 23	**Minimun:** 21.5		**Average:** 22		**Std. :** 0.52	

Material: AC10 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	60	54	53	57	56	55.5
Sample 2	55	56	57.5	54	55	56
Sample 3	52	57.5	54	53.5	53	52
Maximum: 60	**Minimum:** 52		**Average:** 55		**Std. :** 2.05	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	53	54.5	52.5	55	56	54
Sample 2	57	56.5	54	56.5	54	55
Sample 3	52.5	55	54.5	57	57	55
Maximum: 57	**Minimun:** 52.5		**Average:** 55		**Std. :** 1.44	

Material: AC20 **Addition:** Carbon Black

Temperature: 59°F/15°C **Percentage:** 20%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	20	19	20	20		
Sample 2	20	20	20.5	20		
Sample 3	19	18.5	19.5	19		
Maximum: 20.5	**Minimum:** 18.5		**Average:** 20		**Std. :** 0.58	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	20	19	19	19		
Sample 2	19	20.5	19.5	19		
Sample 3	19	18.5	19.5	19		
Maximum: 20.5	**Minimun:** 18.5		**Average:** 19		**Std. :** 0.52	

Material: AC20 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 20%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	50	51	49.5	49	52	49
Sample 2	47	49.5	50	53	49.5	49
Sample 3	51	48	48.5	50	52	50
Maximum: 53	**Minimum:** 47		**Average:** 50		**Std. :** 1.45	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	46.5	47.5	48	50	46	45
Sample 2	45.5	48	47.5	45	46.5	47
Sample 3	57	50	55.5	46	53	48.5
Maximum: 57	**Minimun:** 45		**Average:** 48		**Std. :** 3.37	

b.2 Penetration Test on Asphalt Modified by Pyrolyzed Carbon Black

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 0%

Top of Box	1	2	3	4	5	6
Sample 1	39	38	40	40		
Sample 2	38	39	40	40		
Sample 3						
Maximum: 40	**Minimum:** 38		**Average:** 39		**Std. :** 0.83	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 0%

Top of Box	1	2	3	4	5	6
Sample 1	103	106	104	105		
Sample 2	106	102	102	101		
Sample 3						
Maximum: 106	**Minimum:** 101		**Average:** 104		**Std. :** 1.80	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 5%

Top of Box	1	2	3	4	5	6
Sample 1	35	38	36	37	35	37
Sample 2	34	35	34	34	36	35
Sample 3	35	36	35	34	34	37
Maximum: 38	**Minimum:** 34		**Average:** 35		**Std. :** 1.21	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	35	33	32	35	29	33
Sample 2	38	40	37	38	35	36
Sample 3	34	36	34	36	34	37
Maximum: 40	**Minimun:** 29		**Average:** 35		**Std. :** 2.47	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 5%

Top of Box	1	2	3	4	5	6
Sample 1	85	105	98	1085	100	100
Sample 2	105	107	99	100	107	100
Sample 3	108	104	100	102	103	102
Maximum: 108	**Minimum:** 98		**Average:** 102		**Std. :** 2.96	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	91	96	96	93	95	98
Sample 2	95	95	96	96	97	95
Sample 3	94	95	90	98	97	84
Maximum: 98	**Minimun:** 84		**Average:** 95		**Std. :** 3.32	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 10%

Top of Box	1	2	3	4	5	6
Sample 1	39	35	35	34	35	37
Sample 2	34	39	35	34	37	35
Sample 3	33	33	33	35	34	32
Maximum: 39	**Minimum:** 32		**Average:** 35		**Std. :** 1.67	
Bottom of Box	1	2	3	4	5	6
Sample 1	33	35	31	33	35	33
Sample 2	32	31	29	36	32	32
Sample 3	30	30	29	29	31	30
Maximum: 36	**Minimun:** 29		**Average:** 32		**Std. :** 2.11	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 10%

Top of Box	1	2	3	4	5	6
Sample 1	93	93	91.5	91.5	94	91
Sample 2	87	94	92	90	93	90
Sample 3	86	88	86	86.5	85	85
Maximum: 94	**Minimum:** 85		**Average:** 90		**Std. :** 2.98	
Bottom of Box	1	2	3	4	5	6
Sample 1	88	89	90	90	88	88
Sample 2	91	85	92	88	89	91
Sample 3	83	84	84	84	86	86
Maximum: 92	**Minimun:** 83		**Average:** 87		**Std. :** 2.68	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	28	32	25	27	28	27
Sample 2	31	33	30	32	30	23
Sample 3	32	30	35	30	31	30
Maximum: 35	**Minimum:** 25		**Average:** 30		**Std. :** 2.39	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	29	30	30	30	31	30
Sample 2	31	28	29	28	29	29
Sample 3	31	29	28	30	29	27
Maximum: 31	**Minimun:** 27		**Average:** 29		**Std. :** 1.13	

Material: AC10 **Addition:** Carbon Black

Temperature: 77°F/25°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	83	80	78	86	83	81
Sample 2	80	82	80	81	79	81
Sample 3	86	86	82	82	81	82
Maximum: 86	**Minimum:** 78		**Average:** 82		**Std. :** 2.08	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	70	78	76	79	83	79
Sample 2	76	77.5	80	75	76	78
Sample 3	76.5	77	79	80.5	78	80
Maximum: 83	**Minimun:** 70		**Average:** 78		**Std. :** 2.70	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 20%

Top of Box	1	2	3	4	5	6
Sample 1	27	27	28	26.5	29	26
Sample 2	27	28	29	29	29	27
Sample 3	25	26	26	26	24	28
Maximum: 29	**Minimum:** 24		**Average:** 27		**Std. :** 1.44	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	25	24	23	19	26	24
Sample 2	30	23	22	26	25	26
Sample 3	22	25	25	27	27	26
Maximum: 30	**Minimun:** 19		**Average:** 25		**Std. :** 2.42	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 20%

Top of Box	1	2	3	4	5	6
Sample 1	67	67.5	67	62	66.5	64
Sample 2	66.5	66.5	71.5	64	66.5	70
Sample 3	67	67	70	66	67	68
Maximum: 71.5	**Minimum:** 62		**Average:** 67		**Std. :** 2.16	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	60	64	65	62	62	66
Sample 2	63	60	68	60	64	66
Sample 3	69	64	65	67	68	65
Maximum: 69	**Minimun:** 60		**Average:** 65		**Std. :** 2.64	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 0%

Top of Box	1	2	3	4	5	6
Sample 1	29	30	29	29		
Sample 2	30	30	29	31		
Sample 3						
Maximum: 31	**Minimum:** 29		**Average:** 29		**Std. :** 0.70	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 0%

Top of Box	1	2	3	4	5	6
Sample 1	67	66	68	68		
Sample 2	67	68	67	67		
Sample 3						
Maximum: 68	**Minimum:** 66		**Average:** 67		**Std. :** 0.66	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1						
Sample 2						
Sample 3						
Maximum:	**Minimun:**		**Average:**		**Std. :**	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 5%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	26	22	23	22	20	24
Sample 2	28	26	24	25	24	28
Sample 3	23	21	26	24	26	25
Maximum: 28	**Minimum:** 20		**Average:** 24		**Std. :** 2.16	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	29	24	24	28	24	24
Sample 2	26	23	23	25	25	23
Sample 3	24	24	24	24	23	24
Maximum: 29	**Minimun:** 23		**Average:** 25		**Std. :** 1.61	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 5%

Top of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	55	61	63	59	58	60
Sample 2	60	64	61	64	58	64
Sample 3	61	63	63	61	61	62
Maximum: 64	**Minimum:** 55		**Average:** 61		**Std. :** 2.36	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	56	60	59	60	59	60
Sample 2	56	55	60	57	56	57
Sample 3	62	62	60	59	61	59
Maximum: 62	**Minimun:** 55		**Average:** 59		**Std. :** 2.07	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 10%

Top of Box	1	2	3	4	5	6
Sample 1	21	22	22	22	23	24
Sample 2	25	17	23	21	22	21
Sample 3	15	23	23	23	25	24
Maximum: 25	**Minimum:** 15		**Average:** 22		**Std. :** 2.45	
Bottom of Box	1	2	3	4	5	6
Sample 1	21	23	24	24	24	23
Sample 2	25	23	26	24	22	23
Sample 3	22	24	19	24	23	22
Maximum: 26	**Minimun:** 19		**Average:** 23		**Std. :** 1.52	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 10%

Top of Box	1	2	3	4	5	6
Sample 1	58	63	61	60	60	58
Sample 2	63	64	63	59	60	60
Sample 3	59	64	59	58	59	57
Maximum: 64	**Minimum:** 57		**Average:** 60		**Std. :** 2.16	
Bottom of Box	1	2	3	4	5	6
Sample 1	56	59	56	60	56	57
Sample 2	54	55	56	57	55	54
Sample 3	58	58	57	54	57	55
Maximum: 60	**Minimun:** 54		**Average:** 56		**Std. :** 1.67	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	22	22	20	22	22	21
Sample 2	24	19	23	22	20	20
Sample 3	22	22	23	19	23	21
Maximum: 24	**Minimum:** 19		**Average:** 22		**Std. :** 1.38	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	22	23	23	24	22	23
Sample 2	22	22	23	20	21	23
Sample 3	25	25	24	25	23	24
Maximum: 25	**Minimun:** 20		**Average:** 23		**Std. :** 1.33	

Material: AC10 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 15%

Top of Box	1	2	3	4	5	6
Sample 1	55	59	58	58	56	55
Sample 2	58	60	58	53	55	59
Sample 3	59	57	57	58	55	58
Maximum: 60	**Minimum:** 53		**Average:** 57		**Std. :** 1.82	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	48	53	54	52	54	53
Sample 2	52	54	53	50	56	58
Sample 3	55	50	53	53	49	58
Maximum: 58	**Minimun:** 48		**Average:** 53		**Std. :** 2.66	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 59°F/15°C **Percentage:** 20%

Top of Box	1	2	3	4	5	6
Sample 1	17	18	13	19	20	18
Sample 2	20	19	20	17	18	17
Sample 3	21	19	21	19	20	17
Maximum: 21	**Minimum:** 13		**Average:** 19		**Std. :** 1.86	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	23	18	17	20	18	18
Sample 2	15	19	17	17	15	16
Sample 3	22	18	20	19	17	18
Maximum: 23	**Minimun:** 15		**Average:** 18		**Std. :** 2.06	

Material: AC20 **Addition:** Pyrolyzed Carbon Black

Temperature: 77°F/25°C **Percentage:** 20%

Top of Box	1	2	3	4	5	6
Sample 1	54	48	43	50	42	45
Sample 2	50	50	47	47	48	47
Sample 3	49	46	46	48	49	48.5
Maximum: 54	**Minimum:** 42		**Average:** 48		**Std. :** 2.81	
Bottom of Box	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	41	43	45	44	44	43
Sample 2	45	44	48	51	46	46
Sample 3	45	48	49	48	47	48
Maximum: 51	**Minimun:** 41		**Average:** 46		**Std. :** 2.46	

b.3 Penetration Test on Aged Asphalt Modified by Commercial Carbon Black

Material: AC10 **Addition:** Carbon Black **Percentage:** 0%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	24	26	26	26		
Sample 2	26	26	26	26		
Maximum: 26	**Minimum:** 24		**Average:** 26		**Std. :** 0.44	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	62	65	65	65		
Sample 2	63	64	65	65		
Maximum: 65	**Minimun:** 62		**Average:** 64		**Std. :** 1.09	

Material: AC10 **Addition:** Carbon Black **Percentage:** 5%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	28	28	27	28		
Sample 2	26	27	27	27		
Maximum: 28	**Minimum:** 26		**Average:** 27		**Std. :** 0.66	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	56	55	56	57		
Sample 2	57	57	57	56		
Maximum: 57	**Minimun:** 55		**Average:** 56		**Std. :** 0.70	

Material: AC10 **Addition:** Carbon Black **Percentage:** 10%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	25	25	25	23		
Sample 2	23	24	25	23		
Maximum: 25	**Minimum:** 23		**Average:** 24		**Std. :** 0.93	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	55	55	56	54		
Sample 2	55	55	53	54		
Maximum: 56	**Minimun:** 53		**Average:** 55		**Std. :** 0.86	

Material: AC10 **Addition:** Carbon Black **Percentage:** 15%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	21	22	24	23		
Sample 2	22	23	22	23		
Maximum: 24	**Minimum:** 21		**Average:** 23		**Std. :** 0.87	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	58	56	56	55		
Sample 2	54	54	54	53		
Maximum: 58	**Minimun:** 53		**Average:** 55		**Std. :** 1.50	

Material: AC10 **Addition:** Carbon Black **Percentage:** 20%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	15	15	15	16		
Sample 2	15	15	15	15		
Maximum: 16	**Minimum:** 15		**Average:** 15		**Std. :** 0.33	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	30	32	31	30		
Sample 2	31	31	32	31		
Maximum: 32	**Minimun:** 30		**Average:** 31		**Std. :** 0.71	

Material: AC20 **Addition:** Carbon Black **Percentage:** 0%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	19	19	19	19		
Sample 2	18	20	19	19		
Maximum: 20	**Minimum:** 18		**Average:** 19		**Std. :** 1.50	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	45	44	45	44		
Sample 2	45	45	45	44		
Maximum: 45	**Minimun:** 44		**Average:** 45		**Std. :** 0.48	

Material: AC20 **Addition:** Carbon Black **Percentage:** 5%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	20	20	20	20		
Sample 2	20	19	19	20		
Maximum: 20	**Minimum:** 19	**Average:** 20		**Std. :** 0.43		
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	43	43	43	42		
Sample 2	43	42	44	42		
Maximum: 44	**Minimun:** 42	**Average:** 43		**Std. :** 0.66		

Material: AC20 **Addition:** Carbon Black **Percentage:** 10%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	19	20	17	20		
Sample 2	20	18	19	20		
Maximum: 21	**Minimum:** 17	**Average:** 19		**Std. :** 1.20		
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	42	40	40	40		
Sample 2	40	37	38	38		
Maximum: 42	**Minimun:** 37	**Average:** 39		**Std. :** 1.49		

Material: AC20 **Addition:** Carbon Black **Percentage:** 15%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	22	21	20	22		
Sample 2	19	20	21	21		
Maximum: 22	**Minimum:** 19		**Average:** 21		**Std. :** 0.97	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	37	38	38	38		
Sample 2	36	38	38	38		
Maximum: 38	**Minimun:** 36		**Average:** 38		**Std. :** 0.70	

Material: AC20 **Addition:** Carbon Black **Percentage:** 20%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	. 20	21	22	20		
Sample 2	22	20	20	20		
Maximum: 22	**Minimum:** 20		**Average:** 21		**Std. :** 0.71	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	45	45	45	45		
Sample 2	44	44	44	44		
Maximum: 45	**Minimun:** 44		**Average:** 45		**Std. :** 0.50	

b.4 Penetration of Aging Test on Asphalt Modified by Pyrolyzed Carbon Black

Material: AC10 **Addition:** Pyrolyzed Carbon Black **Percentage:** 0%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	24	26	26	26		
Sample 2	26	26	26	26		
Maximum: 26	**Minimum:** 24		**Average:** 26		**Std. :** 0.66	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	62	65	65	65		
Sample 2	63	64	65	65		
Maximum: 65	**Minimun:** 62		**Average:** 64		**Std. :** 1.09	

Material: AC10 **Addition:** Pyrolyzed Carbon Black **Percentage:** 5%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	22	23	22	21		
Sample 2	22	22	23	22		
Maximum: 23	**Minimum:** 21		**Average:** 22		**Std. :** 0.60	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	54	55	53	54		
Sample 2	55	54	54	53		
Maximum: 55	**Minimun:** 53		**Average:** 54		**Std. :** 0.71	

Material: AC10 **Addition:** Pyrolyzed Carbon Black **Percentage:** 10%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	22	24	22	22		
Sample 2	23	23	22	20		
Maximum: 24	**Minimum:** 20		**Average:** 22		**Std. :** 1.09	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	50	48	49	51		
Sample 2	49	52	50	52		
Maximum: 52	**Minimun:** 48		**Average:** 50		**Std. :** 1.36	

Material: AC10 **Addition:** Pyrolyzed Carbon Black **Percentage:** 15%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	20	20	21	20		
Sample 2	19	21	21	21		
Maximum: 21	**Minimum:** 19		**Average:** 20		**Std. :** 0.70	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	46	46	46	47		
Sample 2	48	45	50	48		
Maximum: 50	**Minimun:** 45		**Average:** 47		**Std. :** 1.50	

Material: AC10 **Addition:** Pyrolyzed Carbon Black **Percentage:** 20%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	20	19	17	18		
Sample 2	19	20	18	19		
Maximum: 20	**Minimum:** 17		**Average:** 19		**Std. :** 0.97	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	45	45	45	45		
Sample 2	44	44	43	44		
Maximum: 45	**Minimun:** 43		**Average:** 44		**Std. :** 0.70	

Material: AC20 **Addition:** Pyrolyzed Carbon Black **Percentage:** 0%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	19	19	19	19		
Sample 2	18	20	19	19		
Maximum: 20	**Minimum:** 18		**Average:** 19		**Std. :** 0.50	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	45	44	45	44		
Sample 2	45	45	45	44		
Maximum: 45	**Minimun:** 44		**Average:** 45		**Std. :** 0.48	

Material: AC20 **Addition:** Pyrolyzed Carbon Black **Percentage:** 5%

Tmperature: 59°F/15°C	1	2	3	4	5	6
Sample 1	20	20	21	21		
Sample 2	20	20	20	19		
Maximum: 21	Minimum: 19		Average: 20		Std. : 0.60	
Temperature: 77°F/25°C	1	2	3	4	5	6
Sample 1	42	42	45	42		
Sample 2	43	42	42	43		
Maximum: 45	Minimun: 42		Average: 43		Std. : 0.99	

Material: AC20 **Addition:** Pyrolyzed Carbon Black **Percentage:** 10%

Tmperature: 59°F/15°C	1	2	3	4	5	6
Sample 1	20	19	19	19		
Sample 2	20	20	19	19		
Maximum: 20	Minimum: 19		Average: 19		Std. : 0.48	
Temperature: 77°F/25°C	1	2	3	4	5	6
Sample 1	40	41	40	38		
Sample 2	40	38	39	40		
Maximum: 41	Minimun: 38		Average: 40		Std. : 1.00	

Material: AC20 **Addition:** Pyrolyzed Carbon Black **Percentage:** 15%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	15	16	15	16		
Sample 2	15	16	16	16		
Maximum: 16	**Minimum:** 15		**Average:** 16		**Std. :** 0.48	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	33	35	34	35		
Sample 2	35	35	35	36		
Maximum: 36	**Minimun:** 33		**Average:** 35		**Std. :** 0.83	

Material: AC20 **Addition:** Pyrolyzed Carbon Black **Percentage:** 20%

Tmperature: 59°F/15°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	15	13	13	14		
Sample 2	13	15	14	14		
Maximum: 15	**Minimum:** 13		**Average:** 14		**Std. :** 0.78	
Temperature: 77°F/25°C	**1**	**2**	**3**	**4**	**5**	**6**
Sample 1	30	29	31	30		
Sample 2	30	30	31	29		
Maximum: 31	**Minimun:** 29		**Average:** 30		**Std. :** 0.71	

c.1 Softening Point Test on Asphalt Material

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC10	CB 0%	122	123	123	123	123	0.433
AC10	CB 5%	125	126	126	125	126	0.500
AC10	CB10%	128	127	128	128	128	0.433
AC10	CB15%	132	133	132	132	132	0.433
AC10	CB20%	136	136	137	137	137	0.500

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC20	CB 0%	126	126	126	126	126	0.194
AC20	CB 5%	125	126	126	126	126	0.387
AC20	CB10%	130	130	130	130	130	0.000
AC20	CB15%	132	133	133	133	133	0.387
AC20	CB20%	135	136	135	136	136	0.447

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC10	PCB 0%	122	123	123	123	123	0.433
AC10	PCB 5%	124	124	124	124	·124	0.000
AC10	PCB10%	126	126	125	126	126	0.000
AC10	PCB15%	128	129	128	128	128	0.433
AC10	PCB20%	130	131	131	131	131	0.433

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC20	PCB 0%	126	126	126	126	126	0.194
AC20	PCB 5%	126	126	126	126	126	0.025
AC20	PCB10%	127	127	126	127	127	0.387
AC20	PCB15%	129	129	130	130	130	0.447
AC20	PCB20%	131	132	131	132	132	0.447

c.2. Softening Point Test on Aged Asphalt Material

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC10	CB 0%	129	130	130	130	130	0.433
AC10	CB 5%	132	132	131	131	132	0.500
AC10	CB10%	132	132	132	132	132	0.000
AC10	CB15%	135	135	135	135	135	0.000
AC10	CB20%	137	137	137	137	137	0.000

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC20	CB 0%	132	132	132	132	132	0.000
AC20	CB 5%	134	134	133	133	134	0.447
AC20	CB10%	136	136	136	136	136	0.000
AC20	CB15%	140	140	140	140	140	0.000
AC20	CB20%	144	144	144	144	144	0.000

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC10	PCB 0%	129	130	130	130	130	0.433
AC10	PCB 5%	132	132	134	134	133	1.000
AC10	PCB10%	132	132	132	132	132	0.000
AC10	PCB15%	134	134	134	135	134	0.433
AC10	PCB20%	138	137	138	138	138	0.433

Sample	Additive	Set One		Set Two		Average	Std
		R 1	R 2	R 1	R 2		
AC20	PCB 0%	132	132	132	132	132	0.000
AC20	PCB 5%	134	134	135	135	135	0.447
AC20	PCB10%	136	136	137	136	136	0.387
AC20	PCB15%	140	140	140	140	140	0.000
AC20	PCB20%	146	147	146	147	147	0.447

D. Regression of Test Results

ANALYSIS OF UNAGED TEST RESULTS

1. AC10+CB /PCB

(1) Raw data CB_raw PCB_raw CB_reg PCB_reg

AC10+CI t= T=
0.0125 25

PER.	77F	59F	A	PI	Sof	SB
0	101	40	0.04023	-0.03755	50.6	6.56756
5	90	36	0.03979	0.03445	52.2	8.38159
10	84	33	0.04058	-0.09517	53.3	11.6545
15	75	30	0.03979	0.03445	55.6	14.9334
20	68	27	0.04011	-0.01905	58.3	24.3409

AC10+PCB

PER.	77F	59F	A	PI	Sof	SB
0	104	39	0.0426	-0.41486	50.6	9.57783
5	98	35	0.04472	-0.72869	51.1	14.5971
10	88.5	32	0.04418	-0.6512	52.2	16.6379
15	80	29	0.04407	-0.63513	53.3	19.9982
20	67	25	0.04281	-0.44791	55.0	22.07

(2) Regreesion Analysis

(a) Penetration at 77F

Depend.	Indp.1	Indp. 2	Regression Output:			Reg
			Constant		102.85	
101	0	0	Std Err of Y Est		2.66481	102.9
90	5	0	R Squared		0.96812	93.7
84	10	0	No. of Observations		10	84.6
75	15	0	Degrees of Freedom		7	75.5
68	20	0				66.4
104	0	0	X Coefficient(s)	-1.82333	-1.63667	102.9
98	0	5	Std Err of Coef.	0.13761	0.13761	94.7
88.5	0	10				86.5
80	0	15				78.3
67	0	20				70.1

(b) Penetration at 59F

Depend.	Indp. 1	Indp. 2	Regression Output:			Reg
			Constant		39.2	
40	0	0	Std Err of Y Est		0.43644	39.2
36	5	0	R Squared		0.994	36.1
33	10	0	No. of Observations		10	33.1
30	15	0	Degrees of Freedom		7	30.0
27	20	0				26.9
39	0	0	X Coefficient(s)	-0.61333	-0.70667	39.2
35	0	5	Std Err of Coef.	0.02254	0.02254	35.7
32	0	10				32.1
29	0	15				28.6
25	0	20				25.1

(c) Softening points

Depend.	Indp. 1	Indp. 2	Regression Output:			Reg
			Constant		50.6984	
50.6	0	0	Std Err of Y Est		0.31145	50.7
52.2	5	25	R Squared		0.99471	51.9
53.3	10	100	No. of Observations		5	53.5
55.6	15	225	Degrees of Freedom		2	55.7
58.3	20	400				58.3
			X Coefficient(s)	0.1873	0.00952	
			Std Err of Coef.	0.06944	0.00333	

Depend.	Indp. 1	Indp. 2	Regressio Regression Output:			Reg
			Constant		50.5397	
50.6	0	0	Std Err of Y Est		0.09391	50.5
51.1	5	25	R Squared		0.99861	51.2
52.2	10	100	No. of Observations		5	52.1
53.3	15	225	Degrees of Freedom		2	53.4
55.0	20	400				55.0
			X Coefficient(s)	0.09524	0.00635	
			Std Err of Coef.	0.02094	0.001	

(3) Regression Analysis

AC10+CI t= T=
0.0125 25

PER.	77F	59F	A	PI	Sof	SB
0	102.9	39.2	0.04189	-0.30567	50.7	8.8298
5	93.7	36.1	0.0414	-0.22779	51.9	10.2136
10	84.6	33.1	0.04081	-0.13264	53.5	12.5116
15	75.5	30.0	0.04008	-0.01374	55.7	15.9165
20	66.4	26.9	0.03918	0.13909	58.3	20.5343

AC10+PCB

PER.	77F	59F	A	PI	Sof	SB
0	102.9	39.2	0.04189	-0.30567	50.5	8.56046
5	94.7	35.7	0.04239	-0.38361	51.2	10.4633
10	86.5	32.1	0.043	-0.47584	52.1	13.7193
15	78.3	28.6	0.04374	-0.5867	53.4	19.2672
20	70.1	25.1	0.04467	-0.72248	55.0	28.9666

2. AC20+CB /PCB

Legends:
(1) Raw data CB_raw PCB_raw CB_reg PCB_reg

AC20+CI t= T=
0.0125 25

PER.	77F	59F	A	PI	Sof	SB
0	65	27	0.03815	0.31726	52.2	6.31688
5	63.5	27	0.03714	0.50034	52.2	5.26008
10	60	25.5	0.03716	0.49665	54.4	7.81621
15	55	22	0.03979	0.03445	56.1	16.3413
20	49	19.5	0.04002	-0.00269	57.8	22.0159

AC20+PCB

PER.	77F	59F	A	PI	Sof	SB
0	67	30	0.0349	0.92989	52.2	3.42329
5	60	24.5	0.0389	0.18701	52.2	7.19564
10	58	23	0.04017	-0.02826	52.8	9.87255

15	55	22	0.03979	0.03445	54.4	12.4087
20	47	18.5	0.04049	-0.08143	55.6	16.7682

(2) Regreesion Analysis

(a) Penetration at 77F

Depend.	Indp.1	Indp. 2	Regression Output:			Reg
			Constant		66.5	
65	0	0	Std Err of Y Est		1.63481	66.5
63.5	5	0	R Squared		0.95181	62.5
60	10	0	No. of Observations		10	58.5
55	15	0	Degrees of Freedom		7	54.5
49	20	0				50.4
67	0	0	X Coefficient(s)	-0.80333	-0.90667	66.5
60	0	5	Std Err of Coef.	0.08442	0.08442	62.0
58	0	10				57.4
55	0	15				52.9
47	0	20				48.4

(b) Penetration at 59F

Depend.	Indp. 1	Indp. 2	Regression Output:			Reg
			Constant		28.45	
27	0	0	Std Err of Y Est		1.20614	28.5
27	5	0	R Squared		0.91214	26.4
25.5	10	0	No. of Observations		10	24.3
22	15	0	Degrees of Freedom		7	22.2
19.5	20	0				20.1
30	0	0	X Coefficient(s)	-0.41667	-0.49333	28.5
24.5	0	5	Std Err of Coef.	0.06228	0.06228	26.0
23	0	10				23.5
22	0	15				21.1
18.5	0	20				18.6

(c) Softening points

Depend.	Indp. 1	Indp. 2	Regression Output:			Reg
			Constant		51.9524	
52.2	0	0	Std Err of Y Est		0.57121	52.0

52.2	5	25	R Squared		0.97247	52.9
54.4	10	100	No. of Observations		5	54.2
56.1	15	225	Degrees of Freedom		2	55.9
57.8	20	400				58.0
			X Coefficient(s)	0.14127	0.00794	
			Std Err of Coef.	0.12736	0.00611	

Depend.	Indp. 1	Indp. 2	Regressio Regression Output:			Reg
			Constant		52.1429	
52.2	0	0	Std Err of Y Est		0.31145	52.1
52.2	5	25	R Squared		0.97817	52.3
52.8	10	100	No. of Observations		5	53.0
54.4	15	225	Degrees of Freedom		2	54.1
55.6	20	400				55.7
			X Coefficient(s)	-0.0127	0.00952	
			Std Err of Coef.	0.06944	0.00333	

(3) Regression Analysis

AC20+CI t= T=

0.0125 25

PER.	77F	59F	A	PI	Sof	SB
0	66.5	28.5	0.03687	0.54965	52.0	4.76373
5	62.5	26.4	0.03747	0.44007	52.9	6.26953
10	58.5	24.3	0.03816	0.31637	54.2	8.9149
15	54.5	22.2	0.03896	0.17562	55.9	13.6201
20	50.4	20.1	0.03992	0.01399	58.0	22.2345

AC20+PCB

PER.	77F	59F	A	PI	Sof	SB
0	66.5	28.5	0.03687	0.54965	52.1	4.93446
5	62.0	26.0	0.03775	0.39027	52.3	5.97557
10	57.4	23.5	0.03878	0.20776	53.0	8.06806
15	52.9	21.1	0.04002	-0.00339	54.1	12.141
20	48.4	18.6	0.04154	-0.2506	55.7	20.3275

ANALYSIS OF AGED TEST RESULTS

1. AC10+CB /PCB

(1) Raw data CB_raw PCB_raw CB_reg PCB_reg

AC10+CI t= T=
0.0125 25

PER.	77F	59F	A	PI	Sof	SB
0	64	26	0.03912	0.14874	54.4	11.0686
5	56	27	0.03168	1.60936	55.6	3.09161
10	55	24	0.03602	0.71139	55.6	7.58873
15	55	23	0.03786	0.36923	57.2	13.9345
20	45	21	0.0331	1.29958	58.3	6.51125

AC10+PCB

PER.	77F	59F	A	PI	Sof	SB
0	54	26	0.03174	1.59599	54.4	2.60351
5	54	22	0.039	0.16999	56.1	14.2699
10	50	22	0.03565	0.78075	55.6	7.08018
15	47	20	0.03711	0.50663	56.7	11.1341
20	44	19	0.03647	0.62513	58.9	13.8825

(2) Regreesion Analysis

(a) Penetration at 77F

Depend.	Indp.1	Indp. 2	Regression Output:			Reg
			Constant		59	
64	0	0	Std Err of Y Est		3.42122	59.0
56	5	0	R Squared		0.74898	56.4
55	10	0	No. of Observations		10	53.7
55	15	0	Degrees of Freedom		7	51.1
45	20	0				48.5
54	0	0	X Coefficient(s)	-0.52667	-0.79333	59.0
54	0	5	Std Err of Coef.	0.17667	0.17667	55.0
50	0	10				51.1
47	0	15				47.1
44	0	20				43.1

(b) Penetration at 59F

Depend.	Indp. 1	Indp. 2	Regression Output:			Reg
			Constant		26	

26	0	0	Std Err of Y Est		1.17918	26.0
27	5	0	R Squared		0.85253	24.9
24	10	0	No. of Observations		10	23.9
23	15	0	Degrees of Freedom		7	22.8
21	20	0				21.7
26	0	0	X Coefficient(s)	-0.21333	-0.38667	26.0
22	0	5	Std Err of Coef.	0.06089	0.06089	24.1
22	0	10				22.1
20	0	15				20.2
19	0	20				18.3

(c) Softening points

Depend.	Indp. 1	Indp. 2	Regression Output:			Reg
			Constant		54.5714	
54.4	0	0	Std Err of Y Est		0.44046	54.6
55.6	5	25	R Squared		0.95918	55.2
55.6	10	100	No. of Observations		5	56.0
57.2	15	225	Degrees of Freedom		2	57.0
58.3	20	400				58.3
			X Coefficient(s)	0.09365	0.00476	
			Std Err of Coef.	0.09821	0.00471	

Depend.	Indp. 1	Indp. 2	Regression Output:			Reg
			Constant		54.8413	
54.4	0	0	Std Err of Y Est		0.83466	54.8
56.1	5	25	R Squared		0.87175	55.2
55.6	10	100	No. of Observations		5	55.9
56.7	15	225	Degrees of Freedom		2	57.1
58.9	20	400				58.6
			X Coefficient(s)	0.03016	0.00794	
			Std Err of Coef.	0.1861	0.00892	

(3) Regression Analysis

AC10+CE	t=	T=
	0.0125	25

PER.	77F	59F	A	PI	Sof	SB
0	59.0	26.0	0.03559	0.79372	54.6	5.93366
5	56.4	24.9	0.03542	0.8256	55.2	6.34138
10	53.7	23.9	0.03525	0.86067	56.0	7.0078
15	51.1	22.8	0.03505	0.89946	57.0	7.9803
20	48.5	21.7	0.03483	0.94258	58.3	9.32698

AC10+PCB

PER.	77F	59F	A	PI	Sof	SB
0	59.0	26.0	0.03559	0.79372	54.8	6.20937
5	55.0	24.1	0.03592	0.72942	55.2	7.01836
10	51.1	22.1	0.03631	0.65548	55.9	8.53801
15	47.1	20.2	0.03677	0.56953	57.1	11.1546
20	43.1	18.3	0.03732	0.4684	58.6	15.6018

2. AC20+CB /PCB

Legends:

(1) Raw data CB_raw PCB_raw CB_reg PCB_reg

AC20+CE t= 0.0125 T= 25

PER.	77F	59F	A	PI	Sof	SB
0	45	19	0.03745	0.44461	55.6	9.90899
5	43	20	0.03324	1.26891	56.7	5.1952
10	39	19	0.03123	1.71164	57.8	3.96473
15	38	21	0.02576	3.11291	60.0	1.35547
20	31	15	0.03153	1.64437	62.2	8.00831

AC20+PCB

PER.	77F	59F	A	PI	Sof	SB
0	45	19	0.03745	0.44461	55.6	9.90899
5	43	20	0.03324	1.26891	57.2	5.6672
10	40	19	0.03233	1.46556	57.8	5.07089
15	35	16	0.03399	1.11218	60.0	10.023
20	30	14	0.0331	1.29958	63.9	14.0734

(2) Regreesion Analysis

(a) Penetration at 77F

Depend.	Indp.1	Indp. 2	Regression Output:			Reg
			Constant		46	
45	0	0	Std Err of Y Est		1.35401	46.0
43	5	0	R Squared		0.95192	42.6
39	10	0	No. of Observations		10	39.3
38	15	0	Degrees of Freedom		7	35.9
31	20	0				32.5
45	0	0	X Coefficient(s)	-0.67333	-0.74667	46.0
43	0	5	Std Err of Coef.	0.06992	0.06992	42.3
40	0	10				38.5

35	0	15	34.8
30	0	20	31.1

(b) Penetration at 59F

Depend.	Indp. 1	Indp. 2	Reg
19	0	0	20.3
20	5	0	19.6
19	10	0	18.8
21	15	0	18.1
15	20	0	17.4
19	0	0	20.3
20	0	5	18.9
19	0	10	17.6
16	0	15	16.2
14	0	20	14.8

Regression Output:

Constant		20.3
Std Err of Y Est		1.75391
R Squared		0.56586
No. of Observations		10
Degrees of Freedom		7
X Coefficient(s)	-0.14667	-0.27333
Std Err of Coef.	0.09057	0.09057

(c) Softening points

Depend.	Indp. 1	Indp. 2	Reg
55.6	0	0	55.6
56.7	5	25	56.5
57.8	10	100	58.0
60.0	15	225	59.9
62.2	20	400	62.3

Regression Output:

Constant		55.5873
Std Err of Y Est		0.18781
R Squared		0.99754
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	0.14286	0.00952
Std Err of Coef.	0.04188	0.00201

Depend.	Indp. 1	Indp. 2	Reg
55.6	0	0	55.9
57.2	5	25	56.5
57.8	10	100	58.0
60.0	15	225	60.4
63.9	20	400	63.7

Regressio Regression Output:

Constant		55.873
Std Err of Y Est		0.66402
R Squared		0.97868
No. of Observations		5
Degrees of Freedom		2
X Coefficient(s)	0.03968	0.01746
Std Err of Coef.	0.14805	0.0071

(3) Regression Analysis

AC20+CI	t=	T=
	0.0125	25

PER.	77F	59F	A	PI	Sof	SB
0	46.0	20.3	0.03553	0.80571	55.6	6.94159
5	42.6	19.6	0.03382	1.1476	56.5	5.74858
10	39.3	18.8	0.03191	1.55854	58.0	4.75649
15	35.9	18.1	0.02974	2.06234	59.9	3.80588
20	32.5	17.4	0.02726	2.6954	62.3	2.81148

AC20+PCB

PER.	77F	59F	A	PI	Sof	SB
0	46.0	20.3	0.03553	0.80571	55.9	7.27191
5	42.3	18.9	0.03488	0.93352	56.5	7.0851
10	38.5	17.6	0.03411	1.08756	58.0	7.67299
15	34.8	16.2	0.03321	1.27683	60.4	8.99436
20	31.1	14.8	0.03211	1.51508	63.7	11.002

APPENDIX B

PERFORMANCE OF PAVEMENT WITH CB_p MODIFIED ASPHALT CEMENT

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1 INTRODUCTION

The laboratory study of the properties of asphalt cements modified by pyrolyzed carbon black (CB_p) indicated an improved temperature susceptibility of the binders (Zeng and Lovell, 1995). During the course of this project, experimental sections were constructed on State Road 46 to demonstrate the performance of pavement constructed using CB_p modified asphalt binder under actual traffic loads and climate conditions.

In order that the performance data be comparable, three sections of the experimental pavements were constructed on SR 46, using different asphalt binders. The location of these sections is shown in Figure 1. The length of the first section is 3.45 miles, and it was constructed using conventional AC-20 as asphalt binder. The length of the second portion is 3.8 miles, constructed with modified AC-10 (MAC-10). The length of the last section is 3.5 miles, and the binder is CB_p modified MAC-10. (MAC-10/CB_p).

Two inspections have been accomplished for the pavements since construction in September 1993. The first one was carried out in September 1994, and the second one on October 16, 1995. The purpose of the measurements was to examine the performance of the pavement under service conditions, and distinguish the performance of the pavement using MAC-10/CB_p from those with the other two asphalt binders. The inspection done in 1994 indicated that the condition of the three experimental sections was fairly good due to the relatively short service time, even though the quality control on the sections is poor.

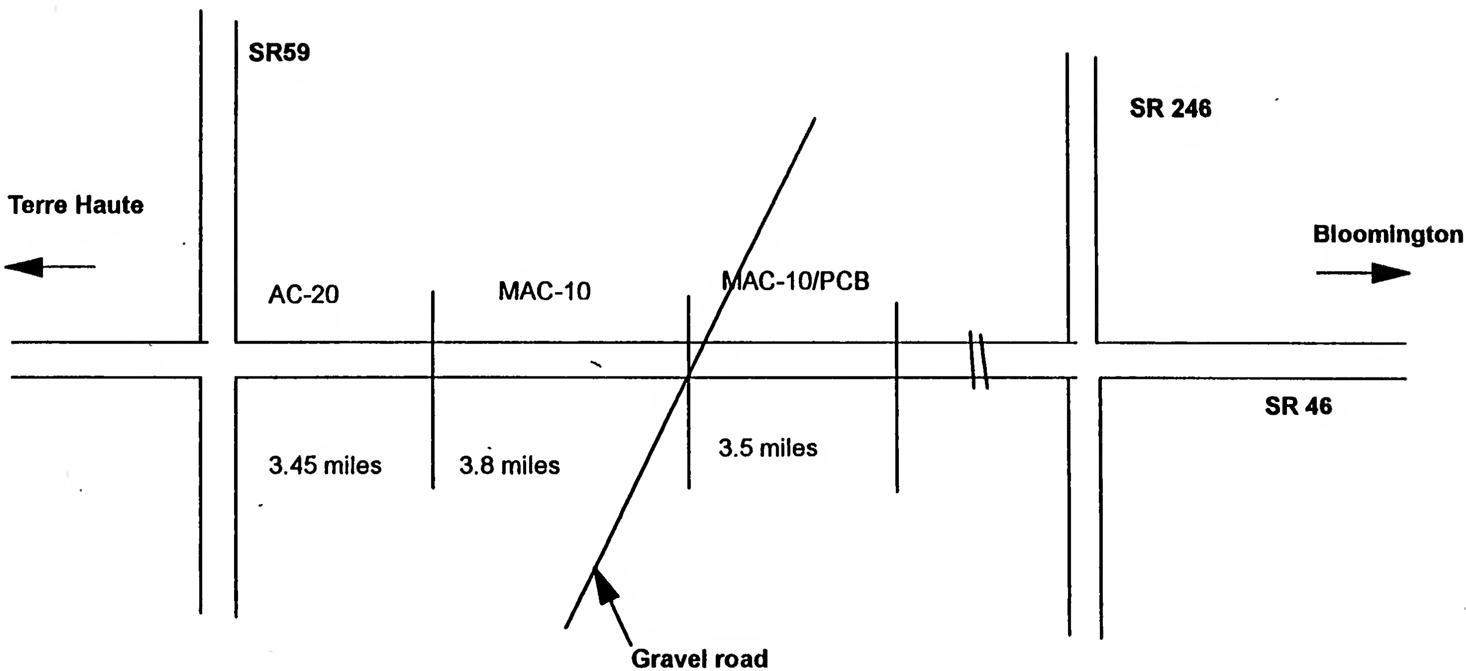


Figure 1. Location of the experimental sections

2 MEASUREMENT

2.1 Distress Types

The 19 possible types of distress of asphalt pavement under long-term traffic loads and the changes of the climate conditions are described in detail in the "Maintenance and Repair Alternatives Pavement Condition Index (PCI) Field Manual" (Shahin, M. Y.). Previous measurement of the test pavements had shown that most of the 19 distress types were not present

Considering the specific purpose of this project, the types of distresses inspected were restricted to the following 4 types:

(1) Alligator cracking

These are interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading. The cracks initialize because of the high tensile stress and strain under a wheel load, and then propagate to the surface of the pavement.

(2) Longitudinal and transverse cracking

Longitudinal cracks are parallel to the pavement's center line or laydown direction. They may be caused by a poorly constructed paving lane joint or shrinkage of the AC surface due to low temperature or hardening of the asphalt.

(3) Rutting

Rutting stems from a permanent deformation in any of the pavement layers or subgrades. Usually, they are caused by consolidated or lateral movement of the materials due to traffic load.

(4) Edge Cracking

Edge cracking is accelerated by traffic loading and can be caused by frost weakened base or subgrade near the edge of the pavement. This distress is very common in almost all pavements.

The severity levels which distresses have on ride quality are described as Low, Medium and High.

2.2 Inspection Results

The inspection was accomplished on October 16, 1995. For every approximate 3.5 miles long pavement section, a sample area of 2400 ft^2 was chosen for every 0.5 mile. The results are presented

in Appendix A and Tables 1, 2 and 3.

Table 1. Inspection results of pavement section #1 (7 random samples)

Binder Type: AC-20

No.	Distress Type	Length (ft)	Density (%)	Severity	Deduction Factor	PCI
1	Long. & Trans.*	18	0.75	Low	1	99 (Excellent)
2	Long. & Trans.	33	1.375	Low	4	96 (Excellent)
3	Long. & Trans.	0				100(Excellent)
4	Long. & Trans.	30	1.25	Low	3	97 (Excellent)
5	Long. & Trans.	28	1.17	Low	2	98 (Excellent)
6	Long. & Trans.	15	0.625	Low	1	99 (Excellent)
7	Long. & Trans.	28	1.17	Low	2	98 (Excellent)

Note: Long. & Trans.: Longitudinal and Transverse Cracking

Table 2. Inspection results of pavement section #2 (7 random samples)

Binder Type: MAC-10

No.	Distress Type	Length (ft)	Density (%)	Severity	Deduction Factor	PCI
1	Long. & Trans.	48	2.00	Low	4	96 (Excellent)
2	Long. & Trans.	7	0.29	Low		100 (Excellent)
3	Long. & Trans.	0				100 (Excellent)
4	Long. & Trans.	5	0.21	Low		100 (Excellent)
5	Long. & Trans.	0				100 (Excellent)
6	Alligator	1x1	0.05	Low	4	96 (Excellent)
7	Long. & Trans.	0				100 (Excellent)

Table 3. Inspection results of pavement section #3 (7 random samples)

Binder Type: MAC-10/CB_p

No.	Distress Type	Length (ft)	Density(%)	Severity	Deduction	PCI
1	Long. & Trans.	0				100 (Excellent)
2	Long. & Trans.	16	0.67	Low	1	99 (Excellent)
3	Long. & Trans.	0				100 (Excellent)
4	Long. & Trans.	4	0.17	Low		100 (Excellent)
5	Long. & Trans.	36	1.17	Low	2	98 (Excellent)
6	Edge Crack	22	0.32	Low	2	98 (Excellent)
7	Long. & Trans.	5	0.21	Low		100 (Excellent)

3 ANALYSIS OF RESULTS

The test results presented in Table 1 to Table 3 were analyzed using statistical methods. The mean values and standard deviations of the PCI were obtained. The results were tabulated in Table 4.

Table 4. Analysis of the results

Variable	PCI Mean	Sample Size	Std. Deviation
AC-20	98.286	7	1.3801
MAC-10	98.857	7	1.9518
MAC-10/CB_p	99.571	7	0.7868

From the data in Table 4, several conclusions are obtained:

(1) The mean value of the PCI of pavement section using MAC-10/CB_p is higher than those of the other two sections. This indicates a better condition of this pavement section.

(2) The standard deviation of the PCI values do not have much difference. Further analysis indicated that there are no significant pairwise differences among the means, which means that the condition of the three pavement sections are almost the same at this time.

(3) Since the pavement was constructed recently, the time span may not be long enough to produce significant differences between these three sections. Differences may appear after a longer service time.

4 CONCLUSION

The field inspection showed that the overall integrity of Section 3, which is constructed using CB_p modified asphalt cements is better than the other two section constructed with conventional AC-20 and modified AC-10.

However, the statistical results showed little difference between these three sections. This may be contributed to the relatively short period of service time. Based on the current performance of the experimental pavement, it is clear that the pyrolyzed carbon black (CB_p) has no detrimental effect on the pavement, and may be a suitable modifier of the asphalt binder

Further inspections are recommended to monitor the performance of the experimental pavement sections.

REFERENCES

1. M. Y. Sahin, " Asphalt Surfaced Roads and Parking Lots-Maintenance and Repair Alternatives Pavement Condition Index (PCI) Field Manual", 1986

Inspection data sheets

ASPHALT PAVEMENT INSPECTION SHEET

Branch SR-46 Section I

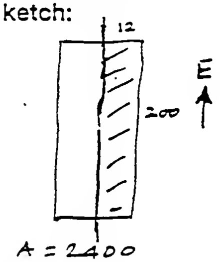
Date 10/16/95 Sample Unit 1

Surveyed by BJC / ZHANG Area of Sample 2400

Distress Types

1. Alligator Cracking	11. Patching & Util Cut Patching
✓ 2. Bleeding	12. Polished Aggregate
3. Block Cracking	*13. Potholes
*4. Bumps and Sags	14. Railroad Crossing
5. Corrugation	15. Rutting
6. Depression	16. Shoving
✓ *7. Edge Cracking	17. Slippage Cracking
*8. Jt Reflection Cracking	18. Swell
*9. Lane/Shldr Drop Off	19. Weathering and Raveling
*10. Long & Trans Cracking	

Sketch:



Existing Distress Types

	10					
	18 L					
Total Severity L	18					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	18/2400×100 Density %	Severity	Deduct Value
10	0.75	L	1
Deduct Total		q =	0
Corrected Deduct Value (CDV)			1

PCI = 100 – CDV = 99

Rating = EXC

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______	Section I
Date ______	Sample Unit 2
Surveyed by ______	Area of Sample ______

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

		10					
		12 L					
		5 L					
		6 L					
		10 L					
Total Severity	L	33 L					
	M						
	H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	1·375	L	4
Deduct Total		q =	
Corrected Deduct Value (CDV)			4

PCI = 100 - CDV = 96

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ____________ Section I

Date ____________ Sample Unit 3

Surveyed by ____________ Area of Sample ____________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

NOTHING

Total Severity	L						
	M						
	H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
Deduct Total	0	q =	
Corrected Deduct Value (CDV)			

PCI = 100 − CDV = 100

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ____________ Section 1 ____________

Date ____________ Sample Unit 4 ____________

Surveyed by ____________ Area of Sample ____________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	6 L					
	24 L					
Total Severity L	30 L					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	1.25	L	3
Deduct Total		q =	
Corrected Deduct Value (CDV)			3

PCI = 100 - CDV = 97

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______ Section I

Date ______ Sample Unit 5

Surveyed by ______ Area of Sample ______

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	6 L					
	4 L					
	12 L					
	3 L					
	3 L					
Total Severity L	28 L					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	1.17	L	2
Deduct Total		q =	
Corrected Deduct Value (CDV)			2

PCI = 100 - CDV = 98

Rating = ______

* All Distresses Are Measured in Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section 1 ______________________

Date ______________________ Sample Unit 6 ______________________

Surveyed by ______________________ Area of Sample ______________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	2 L					
	3 L					
	10 L					
Total Severity L	15 L					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	0.625	L	1
Deduct Total		q =	
Corrected Deduct Value (CDV)			1

PCI = 100 - CDV = 99

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ____________ Section 1

Date ____________ Sample Unit 7

Surveyed by ____________ Area of Sample ____________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	2 L					
	3 L					
	2 L					
	4 L					
	4 L					
Total Severity L	15 L					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	0.625	L	1
Deduct Total		q =	
Corrected Deduct Value (CDV)			1

PCI = 100 − CDV = 99

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section II

Date ______________________ Sample Unit 1

Surveyed by ______________________ Area of Sample ______________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

Longit
Longit

	10					
	19 L					
	29 L					
Total Severity L	48 L					
M						
H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	2	L	4
Deduct Total		q =	
Corrected Deduct Value (CDV)			4

PCI = 100 – CDV = 96

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch __________ Section II

Date __________ Sample Unit 2

Surveyed by __________ Area of Sample __________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	4 L					
	3 L					
Total Severity L	7 L					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	0.29	L	—
Deduct Total		q =	
Corrected Deduct Value (CDV)			—

PCI = 100 – CDV = 100

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section II ______________

Date ______________________ Sample Unit 3 ______________

Surveyed by ______________________ Area of Sample ______________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

NA

Total Severity L						
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
Deduct Total		q =	
Corrected Deduct Value (CDV)			

PCI = 100 - CDV = 100

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section II ______________________

Date ______________________ Sample Unit 4 ______________________

Surveyed by ______________________ Area of Sample ______________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	5 L					
Total Severity L						
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	0.21	L	—
Deduct Total		q =	
Corrected Deduct Value (CDV)			—

PCI = 100 – CDV = 100

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section II ______________

Date ______________________ Sample Unit 5 ______________

Surveyed by ______________________ Area of Sample ______________

Distress Types	Sketch:
1. Alligator Cracking 2. Bleeding 3. Block Cracking *4. Bumps and Sags 5. Corrugation 6. Depression *7. Edge Cracking *8. Jt Reflection Cracking *9. Lane/Shldr Drop Off *10. Long & Trans Cracking 11. Patching & Util Cut Patching 12. Polished Aggregate *13. Potholes 14. Railroad Crossing 15. Rutting 16. Shoving 17. Slippage Cracking 18. Swell 19. Weathering and Raveling	

Existing Distress Types

			N/A			
Total Severity L						
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
Deduct Total		q =	
Corrected Deduct Value (CDV)			

PCI = 100 - CDV = 100

Rating = ______

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ________ Section II

Date ________ Sample Unit 6

Surveyed by ________ Area of Sample ________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	1					
	1x1 L					
Total Severity L	1 L					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
1	0.05	L	4
Deduct Total		q =	
Corrected Deduct Value (CDV)			4

PCI = 100 - CDV = 96

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section ______________________

Date ______________________ Sample Unit II

Surveyed by ______________________ Area of Sample 7

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

N/A

Total Severity L						
M						
H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
Deduct Total		q =	
Corrected Deduct Value (CDV)			

PCI = 100 - CDV = 100

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ____________________ Section III
Date ____________________ Sample Unit 1
Surveyed by ____________________ Area of Sample ____________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Ravelling

Sketch:

Existing Distress Types

NADA

Total Severity L						
M						
H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
Deduct Total		q =	
Corrected Deduct Value (CDV)			

PCI = 100 – CDV = 100

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________ Section III

Date ______________ Sample Unit 2

Surveyed by ______________ Area of Sample ______________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	12 L					
	2 L					
	2 L					
Total Severity L	16 L					
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	0.67	L	1
Deduct Total		q =	
Corrected Deduct Value (CDV)			1

PCI = 100 - CDV = 99

Rating = ______

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section III

Date ______________________ Sample Unit 3

Surveyed by ______________________ Area of Sample ______________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

N/A

Total Severity L						
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
Deduct Total		q =	
Corrected Deduct Value (CDV)			

PCI = 100 - CDV = 100

Rating = ______

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section III

Date ______________________ Sample Unit 3

Surveyed by ______________________ Area of Sample ______________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	4 L					
Total Severity L						
M						
H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	0.17	L	–
Deduct Total		q =	
Corrected Deduct Value (CDV)			–

PCI = 100 – CDV = 100

Rating = ______

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ____________________ Section III

Date ____________________ Sample Unit 45

Surveyed by ____________________ Area of Sample ____________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	4 L					
	12 L					
erdrain	8 L					
	2 L					
	4 L					
	6 L					
Total Severity L						
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	1.17	L	2
Deduct Total		q =	
Corrected Deduct Value (CDV)			2

PCI = 100 – CDV = 98

Rating = ____________________

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ____________________ Section III

Date ____________________ Sample Unit 6

Surveyed by ____________________ Area of Sample ____________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	7					
	22 L					
Total Severity L						
Total Severity M						
Total Severity H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
7	0.37	L	2
Deduct Total	q =		
Corrected Deduct Value (CDV)			2

PCI = 100 − CDV = 98

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

ASPHALT PAVEMENT INSPECTION SHEET

Branch ______________________ Section III

Date ______________________ Sample Unit 47

Surveyed by ______________________ Area of Sample ______________________

Distress Types

1. Alligator Cracking
2. Bleeding
3. Block Cracking
*4. Bumps and Sags
5. Corrugation
6. Depression
*7. Edge Cracking
*8. Jt Reflection Cracking
*9. Lane/Shldr Drop Off
*10. Long & Trans Cracking
11. Patching & Util Cut Patching
12. Polished Aggregate
*13. Potholes
14. Railroad Crossing
15. Rutting
16. Shoving
17. Slippage Cracking
18. Swell
19. Weathering and Raveling

Sketch:

Existing Distress Types

	10					
	3 L					
	2 L					
Total Severity L	5 L					
M						
H						

PCI Calculation

Distress Type	Density	Severity	Deduct Value
10	0.21	L	—
Deduct Total		q =	
Corrected Deduct Value (CDV)			—

PCI = 100 – CDV = 100

Rating =

* All Distresses Are Measured In Square Feet Except Distresses 4, 7, 8, 9, and 10 Which Are Measured In Linear Feet; Distress 13 Is Measured In Number of Potholes.

COVER DESIGN BY ALDO GIORGINI